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Schulze, R.H., G. Wohl, and L. Wallendorf

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This study was conducted to determine the probability of a consequential hazardous substance spill in the St. Marys River area as a result of navigation in both winter and non-winter periods. Specifically, the project develops estimates of the numerical probability of a spill occurring on the St. Marys River and in Whitefish Bay, and the probable type and magnitude of such a spill. The estimates were calculated for the following shipping seasons: 1 April - 15 December; 1 April - 15 January; 1 April - 14 February; 25 March - 15 December; 18 March - 15 December; and Year-round. Keywords

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PROBABILITY OF HAZARDOUS SUBSTANCE SPILLS ON ST. MARYS RIVER

Contract DACW 35-81-C-0076

March 1982

R.H. Schulze
G. Wohl, L. Wallendorf

Submitted to

DEPARTMENT OF THE ARMY
Corps of Engineers
Environmental Analysis Branch
P.O. Box 1027
Detroit, Michigan 48231

Submitted by

ARCTEC, Incorporated
9104 Red Branch Road
Columbia, Maryland 21045

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I. EXECUTIVE SUMMARY

Objectives

1.01 The objective of this study is to determine the probability of a consequential hazardous substance spill in the St. Marys River area as a result of navigation in both winter and non-winter periods. Specifically, the project develops estimates of:

- The numerical probability of a spill occurring on the St. Marys River and in Whitefish Bay

- The probable type and magnitude of such a spill

These estimates are calculated for both winter and non-winter periods in each of the following shipping seasons:

- 1 April to 15 December
- 1 April to 15 January
- 1 April to 14 February
- 25 March to 15 December
- 18 March to 15 December
- Year-round

The St. Marys River/Whitefish Bay Area

1.02 Whitefish Bay is located at the southeast corner of Lake Superior and is the beginning of the area that provides drainage for Lake Superior into the lower Lakes. The St. Marys River begins at the lower end of Whitefish Bay and flows in a generally southeasterly direction through several channels to Lake Huron, a distance of between 63 and 75 miles depending on the route taken. The river drops approximately 22 feet along its course with most the drop (20 feet) occurring at the St. Marys Falls. The Soo Locks, located at Sault Ste. Marie, provide for passage of ships around the St. Marys Falls. The Soo Lock system consists of four parallel locks that can accommodate ships up to 1000 feet long, 105 feet in beam, and a draft of 27 feet.

1.03 A number of seasonal icing problems affect navigation in the St. Marys River and Whitefish Bay. For example, prevailing winds and currents from the northwest, drive pack ice breaking up out of Lake Superior into funnel-shaped sections in Whitefish Bay. These formations present a hazard to navigation during breakup. Winds and currents may also drive slush ice from Lake Superior into the St. Marys River and accumulations may extend from the surface to the bottom. Concentrations of slush ice may close the channel for a period of one to three days.

Operational Assessment of Accident and Spill Potential

1.04 An operational assessment of the hazards of operating in the St. Marys River and Whitefish Bay beyond the limits of the traditional season has been developed by interviewing senior officials in agencies responsible for navigation in this area. This assessment is intended to supplement and verify the mathematical analysis with the judgement of mariners who are experienced operating in the area. Significant comments from these interviews follow.

1.05 Aids to Navigation. Range lights are the primary aid to navigating the St. Marys River. These lights are mounted on fixed structures and are therefore available to the mariner night and day in all seasons, providing visibility is good. The use of range lights as the primary aid to staying in the channel minimizes the effect of channel buoys being removed in the winter.

1.06 Navigation in Ice. The shorefast ice in the St. Marys River usually remains in place until breakup. As a result, ships are constrained to remain in the channel cut in the ice and are therefore not likely to go aground.

1.07 Control of Shipping. Traffic is always controlled in the St. Marys River, but is more strictly controlled in the winter. In addition, when the ice is in place, ships are generally escorted by Coast Guard icebreakers. Positive traffic control plus the escort system reduces the hazards of an accident in the winter.

1.08 Ship's Characteristics. All bulk carrying lakers are double hulled, therefore there is not much chance of an oil spill resulting from a collision. Although ships may be holed from collisions with ice, screw and rudder damage are the more common results of accidents in ice. Tankers, which are the primary threat to a large spill, are generally much smaller than the bulkers and draw less water. As a result, tankers are less likely to have a collision or go aground.

1.09 General Operational Assessment. The officers responsible for the safe navigation in the St. Marys River point out that in winter the presence of ice stops a ship's movement when power is removed and therefore prevents a collision. Assessing the overall risk, Coast Guard officers believe the casualty rate would not be greater in the winter than in the summer.

Spill Potential Based on Ship's Structural Design

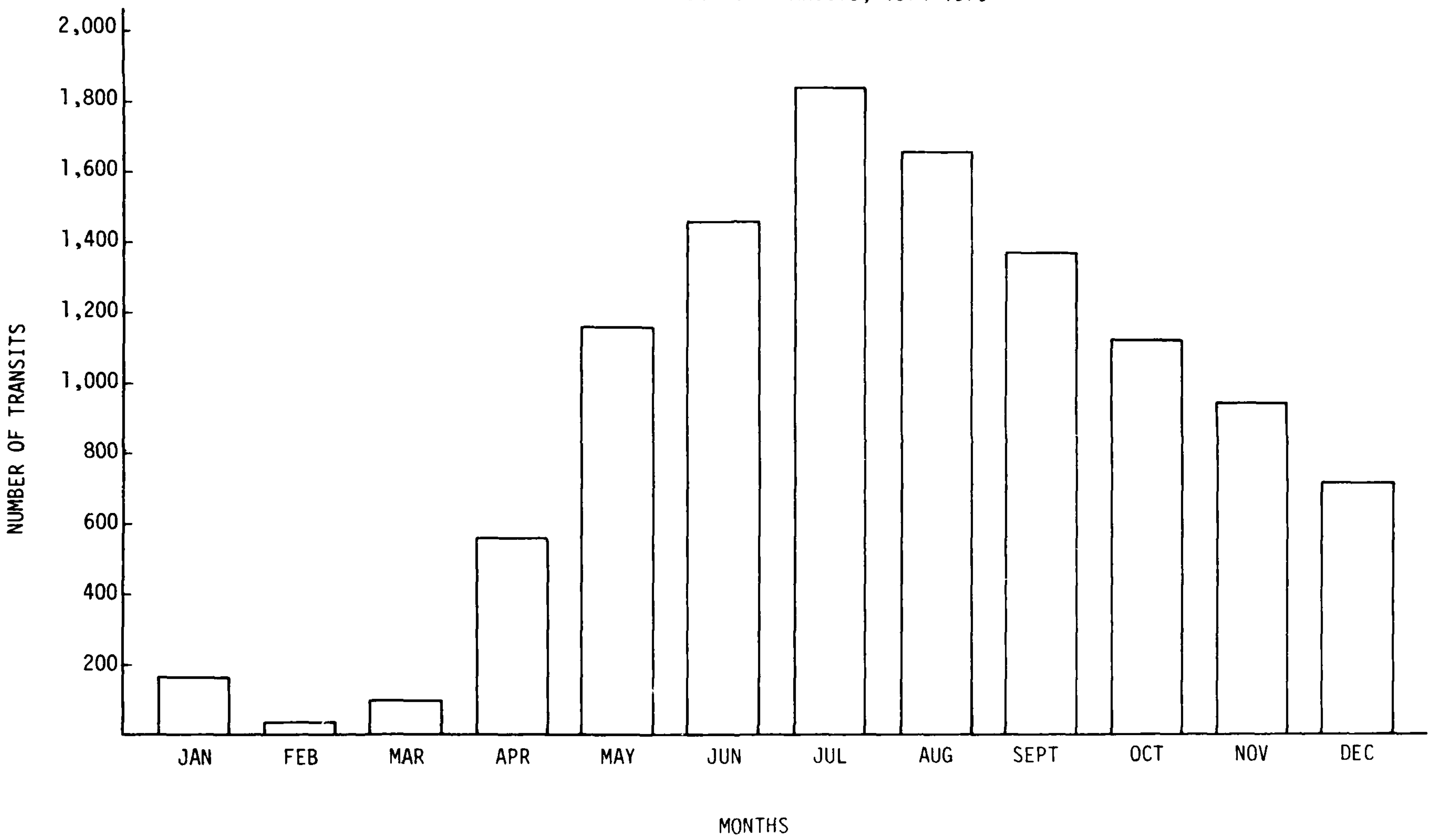
1.10 Fuel tanks on a typical Great Lakes bulker are located well aft and about 4 to 6 feet inside the hull shell. An oil spill resulting from a grounding is unlikely because the ship has a double bottom and the fuel tank is protected from damage by the engine room. All new tankers and tank barges also have double hulls. These ships are constructed with a void tank and cofferdam in the bow so that a collision right at the bow is not likely to result in a spill; however, a grounding with severe damage to the hull could result in spilling an entire tank.

1.11 Because the crushing strength of fresh water ice can be up to four times that of salt water ice, there is danger of hull damage to ships operating in heavy winter ice conditions. The worst ice loading situation is one in which the ship is drifting or swinging at a mooring against a large, landbound flow of ice. In this case the fresh water ice would be constrained against the side of the ship with a crushing strength of three to twelve times the unconstrained sea-ice crushing strength. These situations are very likely to cause hull damage, but since fuel tanks are generally protected by a void space or a double hull, damage to the hull would not necessarily cause a spill.

Vessel Transits, Accidents, and Spills

1.12 The St. Marys River is a choke point to shipping traffic between Lake Superior and the lower Great Lakes. Ports of Lake Superior are the primary source of cargoes that are transported to ports in the lower Lakes and in some cases overseas. Because of this characteristic, the standard measure of vessel activity in the area is the transit or passage of a vessel between Lake Superior and Lake Huron. Figure I-1 shows the average monthly transits for the period of this analysis. The Season Extension Demonstration Program was in operation during this time so that the Soo Locks were open for all but about two and a half months of the period of this report. Figure I-1 shows that shipping activity reaches a peak in July. From this high point, transits fall off gradually through December and reach the lowest level during the heaviest ice months of February and March. Although the navigation season traditionally

FIGURE I-1 AVERAGE MONTHLY TRANSITS, 1974-1979



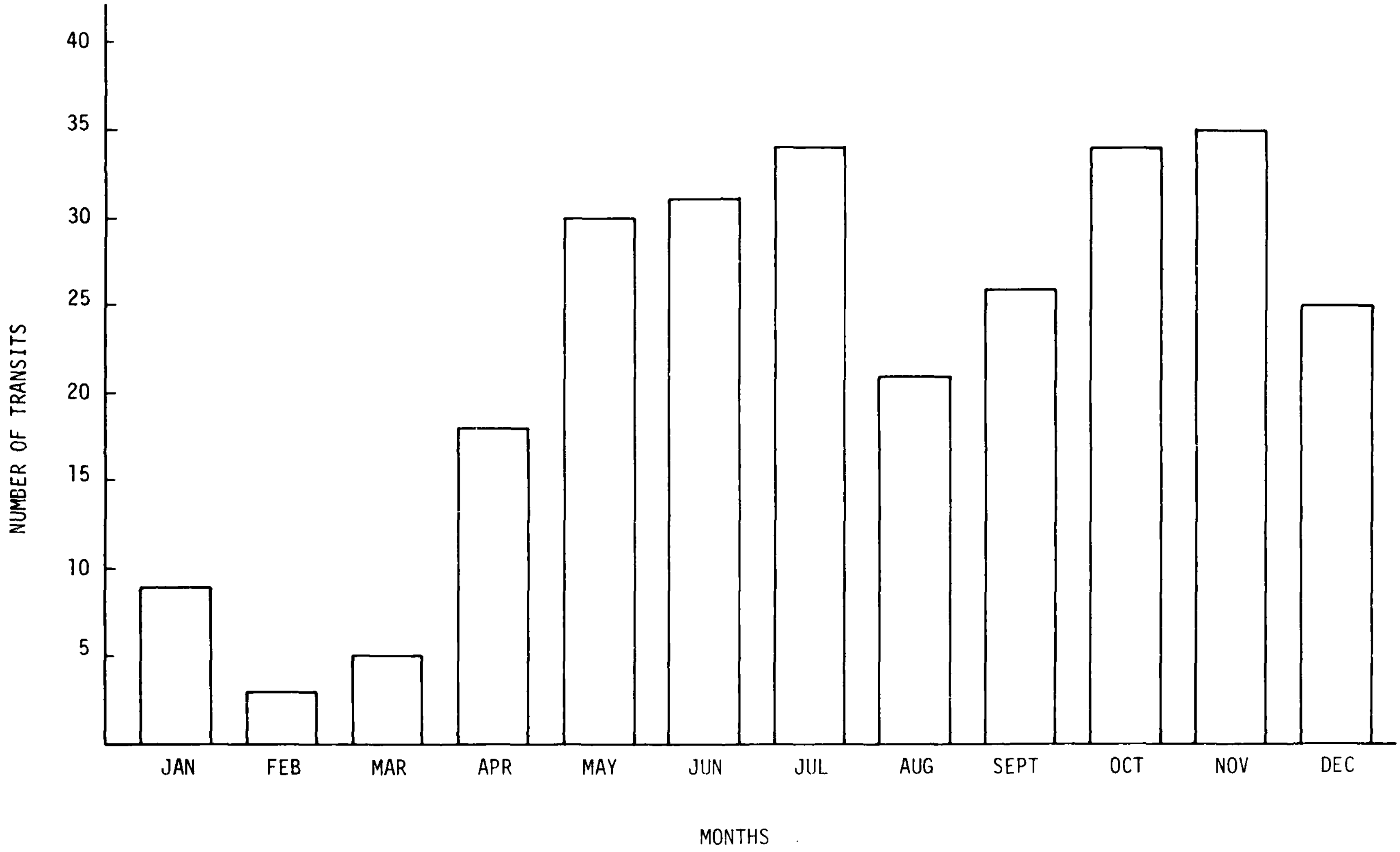
begins in April, the number of transits is generally low because of ice.

1.13 Figure I-2 shows the average number of tanker transits by month for the period of the analysis. As in the case of total transits, tanker transits tend to be low in winter and build to a maximum in July. Tanker activity is different, however, in that there is a sharp drop in transits in August followed by another high point in November. This occurs because the tankers are supplying fuel oil to the cities along Lake Superior. Late season activity shows suppliers building fuel stocks for the winter. Thus the seasonal pattern for tanker transits is much different than for bulkers. In addition, the total annual demand for tanker loads is independent of the general level of activity at the Locks. Total transits through the Locks are tied to the requirement for ore for the steel industry and to a lesser extent the demand for grain overseas. Tanker transits, on the other hand, depend on the local demand for fuel oil and gasoline. This demand depends on winter temperatures in the area and the consumption habits of the residents along the shores of Lake Superior. Note that all tanker cargoes passing through the St. Marys River are refined petroleum products. Crude oil is not transported in this area.

1.14 Ship transits are used in this study to determine the probability of an accident on a single transit. The probability of an accident is computed by dividing the number of reported accidents by the total number of transits that occurred in the same period. Because the probability of an accident is affected by weather conditions, both accidents and transits are classified according to whether they occurred in good visibility conditions or in low visibility conditions. To perform the analysis, it was necesary to use existing transit records to predict the number of tanker transits that would occur in the St. Marys River for the various season extension periods considered in this study. These predictions are based on the average number of tanker transits that occurred during the Season Extension Demonstration Program and the expected future demand for petroleum products.

1.15 Data on vessel accidents used in this analysis are taken from U.S. Coast Guard Casualty Records. To use this data to compute the probability of an accident and a spill, it is necessary to establish categories of accidents that are clearly related to spills and to the basic statistic of the St. Marys River Waterway, which is vessel transits. The accident categories that are established to meet these criteria are groundings, collisions, and collisions with ice. Since visibility is important in determining accident rates, each of these accident categories is further subdivided to show accidents that occur in good visibility and accidents that occur in low visibility.

FUGURE I-2 AVERAGE MONTHLY TANKER TRANSITS, 1974-1979



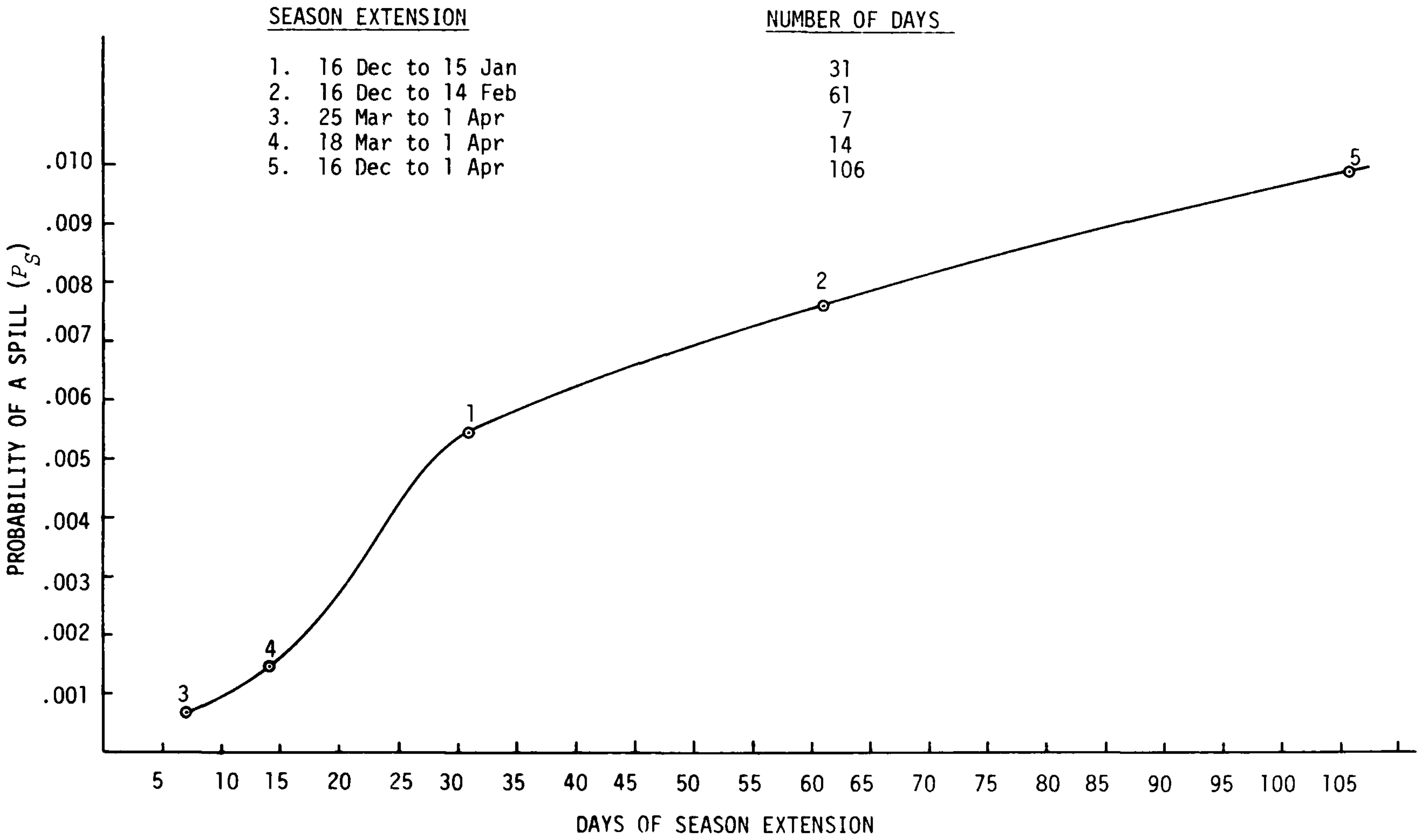
1.16 To predict the probability of a spill during the proposed extended season periods, it is necessary to have spill records that can be used to compute the probability of a spill given an accident. There have been no spills resulting from a grounding or a collision reported for the St. Marys River during the time that separate spill records have been maintained. As a result, it is necessary to analyze a larger population of data to compute the probability of a spill given an accident. Since the greatest threat of a large spill is from a tankship, this study determines the probability of a tankship spill given an accident has occurred for all the Great Lakes and then assumes that the probability of a spill resulting from an accident would be the same for the St. Marys River/Whitefish Bay area. Stated more simply, the assumption is that once an accident occurs, the probability a spill will result is not area dependent. The probability of an accident is area dependent and this study uses accident records for the St. Marys River.

Assessment of Spill Risk

1.17 This study determines spill risk by computing the probability of an accident and a spill for the normal navigation season then uses these results to determine the probability of an accident and spill in the various extended seasons based on the estimated number of transits that would occur in these seasons. By relating the probability of an event to the expected number of transits, it is possible to compute the probability of a spill for any of the season extension alternatives.

1.18 Figure I-3 shows the plot of the probability of a tanker spill in terms of the number of days in each season extension. It is significant to note that in every case, the probability of a spill is very small. For Seasons 3 and 4, which add a few days of navigation at the beginning of the season, the probability of a spill is very low based on a low number of transits expected for an early river opening. Season extension periods 1, 2, and 5 provide a better prediction of what might happen because they represent more substantial additions to the normal season. The probability of a spill during these seasons is relatively low and increases gradually to full season operations. The probability of a spill per day of season extension is actually decreasing as days of season extension are added. The probability of a spill during the additional 106 days that are required for full season operations is about .01, which means there is about a 1 in 100 chance of a tanker spill during this time in any given year. The threat of a spill during extended season operations must therefore be considered to be low.

FIGURE I-3 PROBABILITY OF A TANKER SPILL VS. DAYS OF SEASON EXTENSION



Conclusions

1.19 The probability of a spill resulting from a vessel accident in the St. Marys River/Whitefish Bay area during the proposed extended seasons is low. For full season extension, the probability of an accident is less than 0.2 and the probability of a spill is about 0.01. This means that there is a 1 in 100 chance of a tanker spill during the time added for full season operations. Although the probability of an accident and a spill are low during the extended seasons, the threat of an accident or a spill per transit during late season operations in ice is about three times that of a normal season.

1.20 A tanker grounding is the single significant threat to a large spill. Although the probability of a tanker grounding and spill is low, the spill that may result from this type of accident can be quite large.

1.21 Senior U.S. Coast Guard officers responsible for safe navigation in the St. Marys River believe the threat of a spill from ships operating in ice is low.

1.22 An engineering analysis indicates that there is a danger of a ship being holed by collision with ice or from the crushing force of ice, but because most ships have double hulls, these accidents do not necessarily result in an oil spill.

Recommendations

1.23 Valuable planning information can be obtained by using records of vessel operations to determine the threat of an oil spill in critical shipping choke points. It is therefore recommended that new computations of spill threat be made periodically to assess the impact of changes in traffic levels and operating practices.

1.24 Because tanker groundings are the single major cause of large spills in the Great Lakes, it is recommended that all possible steps be taken to reduce the risk of grounding in critical vessel traffic areas.

1.25 Since oil spills present a greater threat to the environment in the Great Lakes than in ocean areas, it is recommended that immediate steps be taken to identify technology needed to respond to spills in ice in the St. Marys River, Whitefish Bay, and in other locations in the Great Lakes where severe ice conditions occur and there is the threat of a spill.

II. PROJECT DESCRIPTION

Objectives

2.01 Proposals to extend the navigation season in the Great Lakes present the possibility of increased risk of spills of oil and hazardous substances. The objective of this study is to determine the probability of a consequential hazardous substance spill in the St. Marys River area as a result of navigation in both winter and non-winter periods. Specifically, the project develops estimates of:

- *The numerical probability of a spill occurring on the St. Marys River and in Whitefish Bay*
- The probable type and magnitude of such a spill

These estimates are calculated for both winter and non-winter periods in each of the following shipping seasons:

- 1 April to 15 December
- 1 April to 15 January
- 1 April to 14 February
- 25 March to 15 December
- 18 March to 15 December
- Year-round

2.02 Data gathered and estimated for these seasons are for average ice conditions.

Development of Study Analysis

2.03 The St. Marys River serves as an avenue for the flow of traffic from the ports of Lake Superior to the lower Great Lakes. Because of this characteristic, the standard measure of vessel activity in the area is the transit or passage of a vessel between Lake Superior and Lake Huron. This analysis therefore relates the probability of a vessel accident and spill to the total number of transits of ships through the St. Marys

River during a normal season. The normal season is established as a baseline. Using data developed in this baseline, the probability of an accident and a spill are then computed for the extended season alternatives to determine the possible hazards of late season operations.

2.04 Obtaining transit data for the St. Marys River is a key element in performing this analysis. Records of vessels passing through the Soo Locks are the principal source of transit data. These records are particularly useful because they identify traffic according to ship type and commodity. The disadvantage of using these records is that they only include the vessels that actually go through the Locks. A check into the actual flow of traffic in the St. Marys River indicates that many tanker vessels transit the River as far as Sault Ste. Marie, Ontario but do not go through the Locks. No long-term records of this traffic have been found; however, these transits have been estimated by contacting all of the fleet operators that call at Sault Ste. Marie, Ontario for an estimate of the annual traffic they have visiting that port. These estimates are used to account for the traffic that does not pass through the Locks.

2.05 In order to compute the probability of an accident and a spill during the proposed extended seasons, it is first necessary to estimate the number of vessel transits that would occur during these seasons. Records of transits that occurred during the Season Extension Demonstration Program are used as a starting point to estimate the transits for the season extension alternatives. The Season Extension Demonstration records are useful because during this program the Soo Locks were open into February for three years (1972 to 1974) and for 12 months for the remaining years of 1975 through 1978 (1). Additional data for the proposed season extension alternatives are available from the 1979-80 season when the locks were closed 15 January 1980 and from the 1980-81 season, when operations were halted on 31 December 1980. Although the data from the Season Extension Demonstration are useful, some adjustments are required because the number of transits that occurred during this time are fairly small. Also, the Season Extension was basically a full year test and therefore the data does not conform exactly to the alternatives investigated in this analysis. In spite of these problems, the records of transits that occurred during the Season Extension Program provide a good indication of the number of vessel transits that might occur in the winter months. These records are therefore used to estimate the expected number of transits for the proposed season alternatives.

2.06 Estimates of transits for the proposed extended seasons were also checked against a North Central Division, Corps of Engineers study titled the "Great Lakes/St. Lawrence Seaway Lock Capacity Analysis" (2). This study used a computer model to analyze lock capacity for estimated levels of commodity flow in four extended season periods. Two of the extended season periods are the same as those addressed in the current analysis. The other extended seasons have been adapted to cover the extended seasons defined for the present study.

2.07 The numerical analysis in this study begins with computation of the probability of a vessel accident on an individual transit. This is done by dividing the recorded number of accidents by the number of transits. The accidents are related to the weather conditions in which they occurred so that a separate probability can be determined for accidents in good visibility conditions and accidents in reduced visibility conditions. Using these values, the probability of an accident is computed according to visibility conditions for the extended season options by knowing the average number of days that low visibility occurs during these seasons. This refinement improves the accuracy of predicting casualties during the proposed extended season periods.

2.08 After computing the probability of an accident, it is then necessary to compute the probability of a spill given an accident has occurred. This is done by dividing the number of spills by the number of accidents. The probability of a spill given an accident is then combined with the probability of an accident to obtain the probability of a spill. This computation is performed for each of the extended season alternatives.

2.09 The number of accidents that occurred during the Extended Season Demonstration is small, in some cases too small to be statistically significant. Because of this low experience level, the numerical computation of the probability of an accident and a spill has been checked using an engineering analysis of typical ship encounters with ice. This engineering analysis estimates the extent of damage a ship may suffer as a result of a collision with ice and the chance that this damage could result in a spill of a petroleum product or a hazardous substance.

2.10 Finally, the results of the statistical analysis and the engineering analysis are supplemented by an operational assessment of likely accident situations that could occur during extended season operations. This assessment has been obtained through interviews with the Coast Guard officers who are responsible for safe navigation in the St. Marys River and Whitefish Bay. Interviews were obtained from senior Coast Guard officers stationed at Sault Ste. Marie, Michigan, officers on the staff of the Chief of Operations, 9th Coast Guard District, Cleveland, officers from Coast Guard Headquarters in Washington, and commanding officers of Coast Guard icebreakers stationed on the St. Marys River. This operational assessment of extended season operations has been used to verify and confirm the results of the statistical analysis.

III. GENERAL DESCRIPTION OF ST. MARYS RIVER/WHITEFISH BAY AREA

Whitefish Bay

3.01 Whitefish Bay is located at the southeast corner of Lake Superior and is the beginning of the area that provides drainage for Lake Superior into the lower lakes. The Bay begins at Whitefish Point, a prominent navigational landmark, and continues south and southeast for a distance of about 22 miles. The Bay is about 16 miles wide at Whitefish Point and has water depths in the shipping lanes ranging from about 90 to 500 feet.

St. Marys River

3.02 The St. Marys River begins at the lower end of Whitefish Bay at Point Iroquois. The River flows in a generally southeasterly direction through several channels to Lake Huron, a distance of from 63 to 75 miles depending on the route taken. The River drops approximately 22 feet along its course with most of the drop (20 feet) occurring at the St. Marys Falls (3). The outflow of Lake Superior was originally controlled by a rock ledge at the head of the river, but is now regulated by locks, compensating works, and powerhouses.

3.03 Several of the islands in the St. Marys River are inhabited year-round. Transportation to these islands during the winter has traditionally been over the ice or by ferry through an established vessel track. Extending the navigation season in the River causes problems for this winter traffic. Figure III-1 shows the St. Marys River and notes significant points along the channel.

The Soo Locks

3.04 The Soo Locks are located at Sault Ste. Marie, Michigan. Before the Navigation Season Extension program started, the Soo Locks were operated for about nine months each year usually from April through 15 December. During the Season Extension Demonstration Program the Soo Locks were kept open into February for the first three years (1972 to 1974) and for 12 months for the remaining years of 1975 through 1978 (1). The closing date for the 1979-80 season was 15 January 1980, and for the 1980 and 1981 seasons, operations were halted on 31 December.

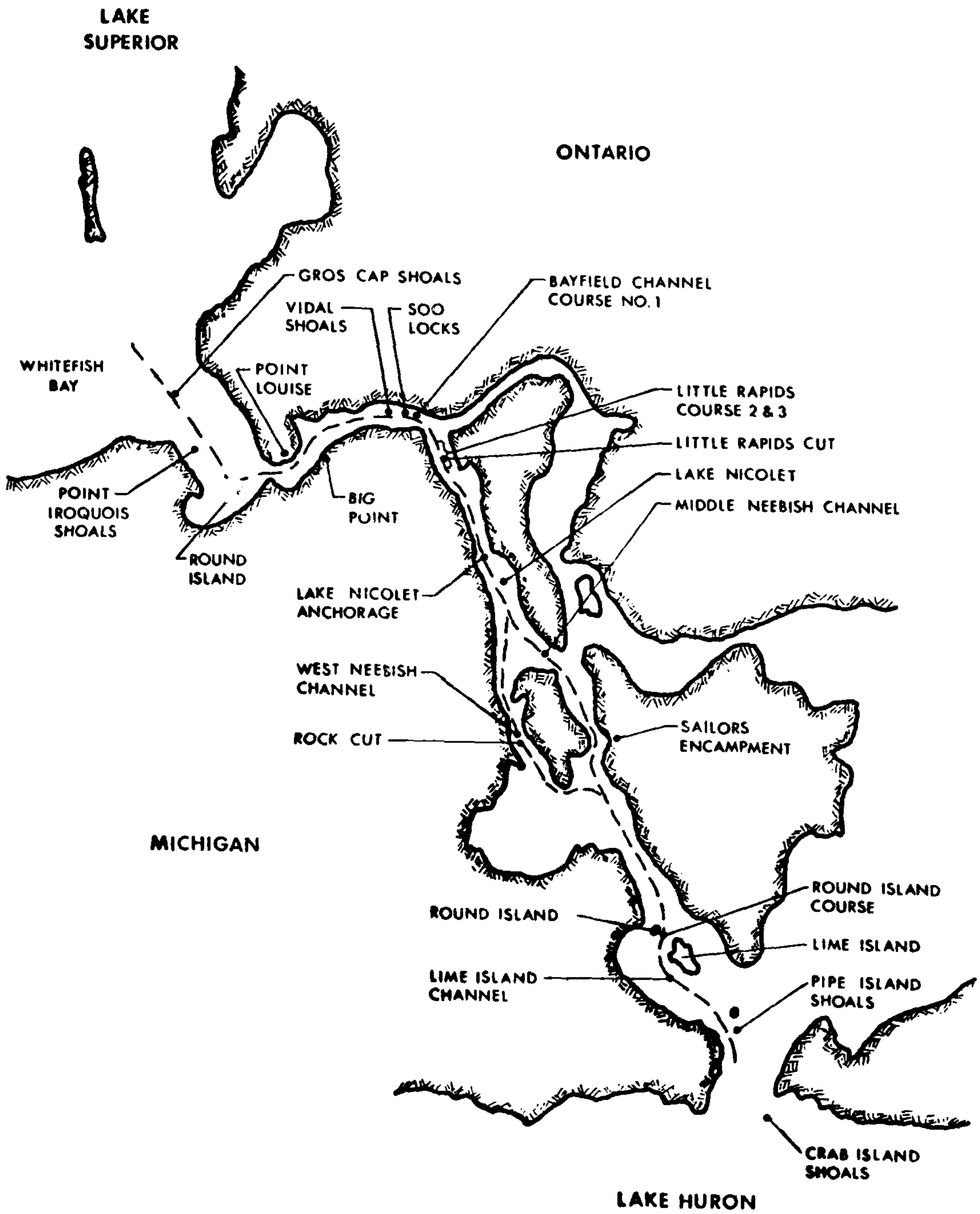


FIGURE III-1 ST. MARYS RIVER CHANNEL

3.05 The Soo Lock system consists of four parallel locks--the MacArthur, Poe, Davis, and Sabin Locks--as shown in Figure III-2. Each lock has its own pier that can accommodate two or three ships in each queue. In addition to the four United States Locks, an older lock is located on the Canadian side of the St. Marys River. Although this lock is small and shallow, it does relieve congestion at the American Locks by handling passenger vessels, pleasure craft, and other small ships carrying cargo.

3.06 Currently, the MacArthur Lock handles most of the downbound loaded ships with an overall length of up to 730 feet and a beam of 75 feet, but can accommodate ships up to 767 feet in length with special locking procedures (4). The Poe Lock can handle ships up to 1100 feet in length with a beam of 105 feet, but currently handles mostly "1000 footers" and all vessels that the MacArthur Lock cannot service. The Sabin and Davis Locks are the same size and handle most of the ballasted upbound ships having a beam of up to 75 feet and length of up to 826 feet. Because of the shallow depth of both the Sabin and Davis Locks, the number of vessels using these Locks has decreased as vessels have either been retired or phased-out of the Great Lakes fleets. As a result, only the Sabin or Davis Lock is usually operated unless there is sufficient demand to warrant the operation of both locks. Table III-1 shows the dimensions of the Soo Locks and ship size restrictions.

St. Marys River Channel Restrictions

3.07 Two bridges cross the St. Marys River near the Soo Locks, and three submarine cables cross elsewhere along the river. The International Railway Bridge has a lift span with a vertical clearance of 123 feet in the raised position. The other bridge is a double-leaf bascule that provides a clear opening when the spans are raised (6).

3.08 Sharp turns in a channel are sometimes hazards to navigation. At three locations in the St. Marys River, the channel width and degree of turn are such that vessels larger than the present 1000 foot length, 105 foot beam "lakers" are not likely to be able to navigate safely. These areas, Sailors Encampment, Little Rapids Cut, and Rock Cut, are shown in Figure III-3 along with the speed limits along the St. Marys River. All speed limits are for speed over the ground rather than speed through the water; therefore, masters must

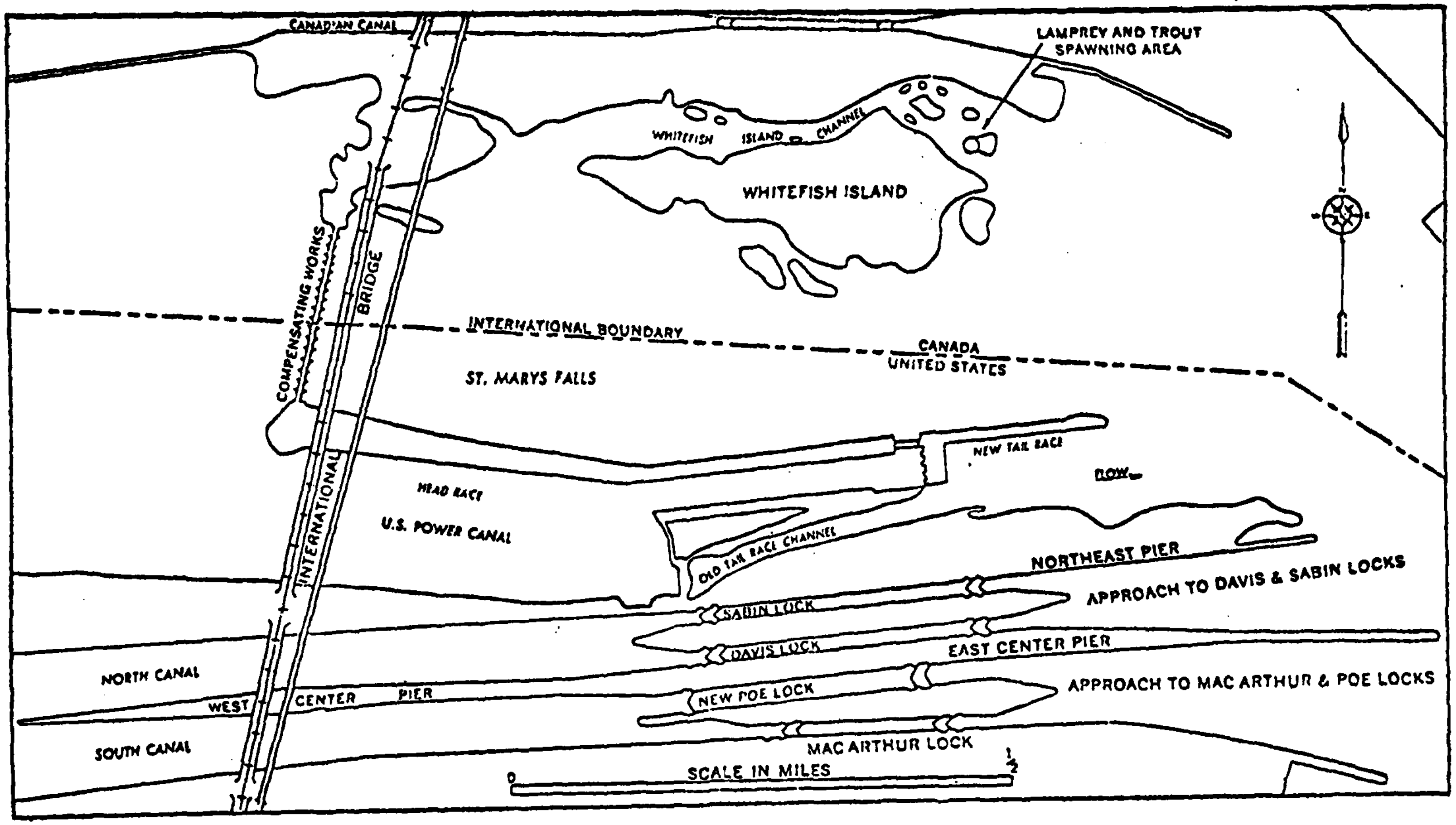


FIGURE III-2 SOO LOCK SYSTEM

TABLE III-1 SOO LOCK DIMENSIONS (4,5)

PRINCIPAL FEATURES	MacARTHUR	SABIN	DAVIS	POE	CANADIAN
Lock width, feet	80	80	80	110	59
Maximum ship beam, feet	75	75	75	105	--
Length between mitre sills, feet	800	1350	1350	1200	900
Maximum ship length, feet	730*	826**	826	1100***	--
Depth on upper mitre sills, feet	31	24.3	24.3	32	16.8
Depth on lower mitre sill, feet	31	23.1	23.1	32	16.8
Lift, feet	22	22	22	22	22

NOTES:

* 767 foot ships permitted with special handling.

** Downbound ships are generally depth-limited in the Sabin-Davis Locks.

*** Normal ship length is 1,000 feet; 1,100 foot ships require specialized locking procedures.

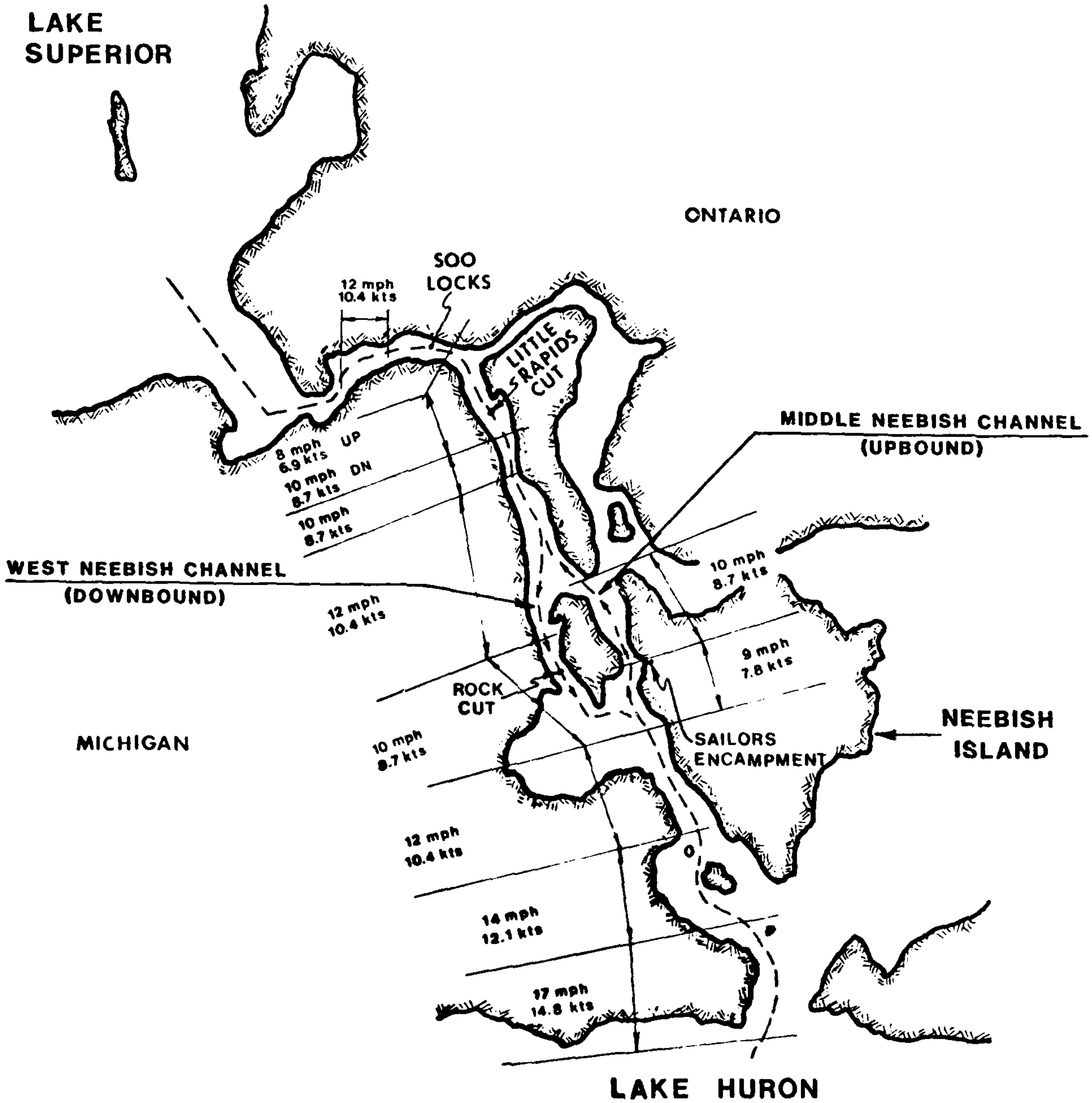


FIGURE III-3 ST. MARYS RIVER CHANNEL - PRINCIPAL TURNS AND SPEED LIMITS (6, 13) determine their speed by time-distance checks rather than by revolutions per minute of the propeller. The currents adjacent to Neebish Island and in Little Rapids Cut vary between 1-1/2 and 2 miles per hour, with an expected low of about 1 mph and a high of about 3 to 3-1/2 mph (6).

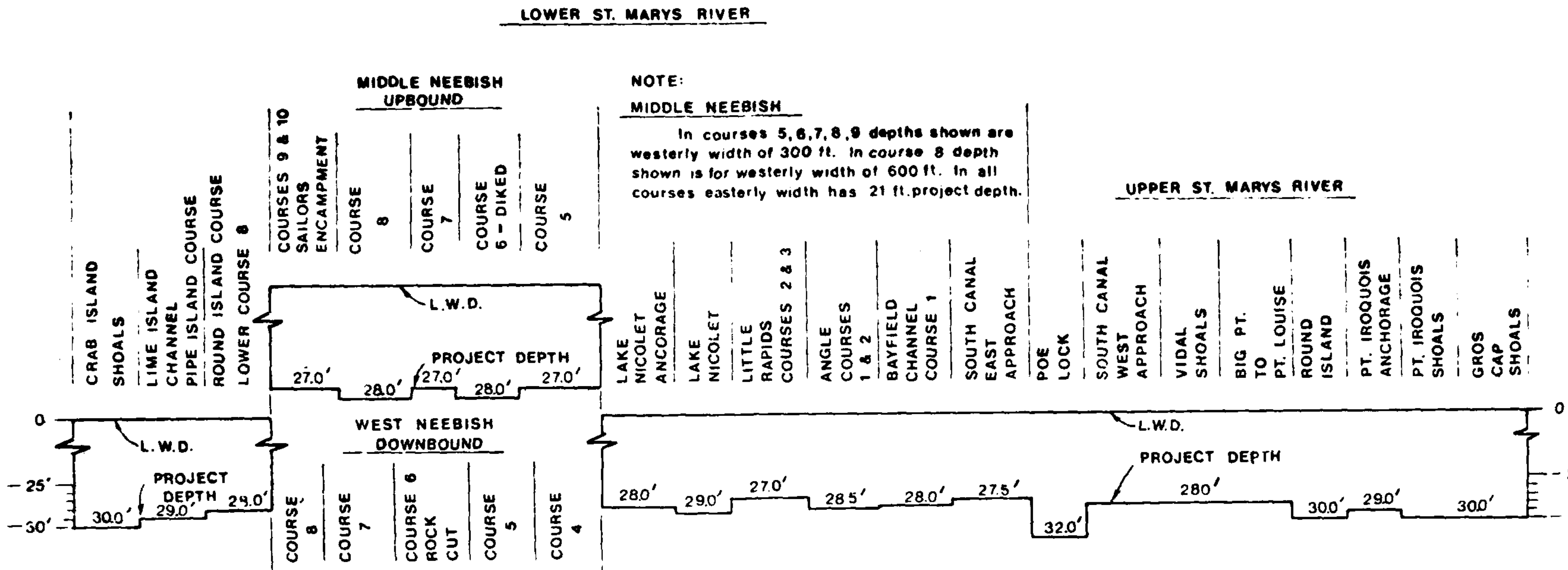
3.9 The reader should be reminded that the speeds shown in Figure III-3 are limits rather than customary speeds of the traffic in the St. Marys River. In winter ice conditions masters proceed slowly and cautiously, far below the published speed limits (7). Tanker captains are the most experienced in operating in ice because there is likely to be late winter demand for their products. Whenever tankers sight ice, they usually slow or stop to determine the nature and extent of the ice before proceeding (7). When vessels are actually in ice, they must maintain high levels of power to continue to move ahead. If they see a dangerous situation developing and take off the power, the vessel stops immediately because of the ice resistance and stays in place. In heavy ice conditions, the danger of the ships momentum carrying it into a collision situation or a grounding is almost entirely removed.

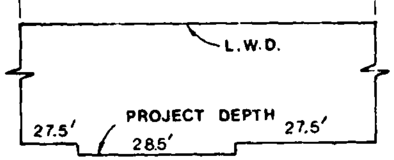
3.10 All of the channels that are not split between upbound and downbound traffic are at least 700 feet wide permitting two way traffic. In the winter all traffic is under positive control and in most areas only one way traffic is permitted.

3.11 The St. Marys River has a minimum project depth of 27 feet. Figure III-4 shows a cross-section of the project depths for the entire channel.

Winter Ice Problems in the St. Marys River and Whitefish Bay

3.12 A number of seasonal icing problems affect navigation in the St. Marys River and Whitefish Bay. One of these problems involves pack ice (3). Pack ice consists of broken pieces of ice that have been consolidated and jammed together by winds and currents. As each winter storm drives more ice into relatively narrow openings, accumulations of pack ice increase in size until they extend as much as 30 feet below the water surface and reach a height of 15 feet or more. Low winter temperatures solidify the upper portions of this mass, which may present an obstruction to navigation during





The connecting channels as authorized provide depths varying from 27 to 30 ft below LWD, depending on exposure of channel, hardness of bottom material, and vessel squat in each reach.

This chart is for information only. These depths are designed to permit maximum draft of 25-1/2 ft for lake vessels when the water level is at LWD. However, the individual vessel Master should give further consideration to the peculiar characteristics of his vessel and to his individual clearance and safety requirements in determining the safe draft to which to load his vessel.

FIGURE III-4 PROJECT DEPTHS IN THE ST. MARYS RIVER (8) extended season operation. Whitefish Bay and the upper St. Marys River are particularly susceptible to formation of pack ice. With prevailing winds from the northwest, solid ice fields are broken up and, together with newly formed ice, are driven into the funnel-shaped sections in Whitefish Bay. These formations present a major hazard to navigation during breakup.

3.13 Ice accumulating along the edge of the channel in the St. Marys River presents problems on turns. A long vessel may be able to move along the restricted space in the ice but not be able to make the turn. Another problem results from the ice in the channel becoming thicker than the fast ice along the shoreline. This occurs because the ice broken by Coast Guard icebreakers or ships is submerged as it is broken then emerges in the wake of the ship as rubble. The rubble is quickly flooded and re-freezes making a deeper layer of ice than before. The result is that the ice may be 2 to 3 feet thick in the channel and only 18 inches thick along the edge. These ice conditions do not prevent winter navigation but simply indicate that icebreaker support is required for full season operations.

3.14 Slush ice can sometimes offer more resistance to navigation than pack ice (3). In some situations, slush ice with a depth of 6 to 8 feet can stop the movement of a lake freighter. In spring, wind and current conditions can drive slush ice from Lake Superior into the St. Marys River so that accumulations extend from the surface to the bottom (4). In these cases the channel may be closed for a period of one to three days (3).

IV. OPERATIONAL ASSESSMENT OF ACCIDENT AND SPILL POTENTIAL

Background

4.01 This study is primarily a statistical analysis of the probability of a spill of a hazardous substance in the St. Marys River or Whitefish Bay. Records of ship casualties and spills are used to determine the probability and frequency of these events. Accident records and statistical information cannot be used alone, however. The assessment of hazards to navigation must also be based on the judgment of experienced mariners who operate in the area. There are several reasons why this is true. First, the accident frequency in this area is low, particularly for tankers. This means that available records may not provide an adequate data base for good statistical results. Second, the probability of an accident and a spill is dependent on a great many variables. These variables include a number of non-statistical parameters such as the qualifications of the ship's crew and fleet operating patterns. Because it is difficult to establish a numerical measure of effectiveness for these parameters, prediction of trends in vessel casualties must be based on the judgment of experienced mariners as well as the records of past performance.

4.02 This section presents an operational assessment of the hazards of operating in the St. Marys River and Whitefish Bay beyond the limits of the traditional season, assumed for this study to be 1 April to 15 December. Emphasis, therefore, is on operating in ice and other winter hazards to navigation. This operational assessment has been developed by interviewing senior officials in the agencies responsible for operations in the St. Marys River. Some of the more important individuals and agencies contacted include the Chief of Operations, 9th Coast Guard District, Cleveland; the Captain of the Port, Sault Ste. Marie, Michigan; the Director of the Great Lakes Pilotage Staff; and the Director of Operations at the Soo Locks. Several other agencies and individuals were also interviewed. These sources can be identified in the footnotes in the sections that follow. The operational assessment of accident and spill potential is divided into sections according to the hazards or problems involved, such as aids to navigation, control of shipping, ice, and so forth.

Aids to Navigation

4.03 Range lights are the primary aid to navigating the St. Marys River (9,10). Each "range" consists of two lights, the more distant light higher than the nearer light, lined up precisely to mark the center of the channel. The ship's master maneuvers his ship so that the higher light is exactly over the lower light, which shows that the ship is on course in the channel. The St. Marys River channel has many sharp turns, so that is possible to mark the center of each channel segment with a set of range lights. These lights are mounted on fixed structures and are therefore available to the mariner night and day and in all seasons, providing visibility is good. In places where there is two way traffic, ranges mark both sides of the channel. In the winter, Coast Guard ice-breakers and lakers cut channels in the ice exactly along these ranges.

4.04 Channel buoys are also an important aid to navigation, but because the buoys may drift out of position, they are not as reliable for navigating as the ranges (9,10). When the normal navigation season ends in the St. Marys River, buoys that would be damaged by ice are removed and replaced with ice buoys in the critical locations. The ice buoys are generally not lighted, but there are some special lighted ice buoys available to mark difficult turns (11). Although winter buoys are important to extended season navigation, they have the dis-advantage of not providing as good a radar target as the regular buoys and they may become obscured by ice and snow. Because many of the buoys are removed in the winter, the use of fixed ranges in the channel becomes even more important. Shippers have requested additional fixed structures with lighted markers in the water for winter navigation. Some of these structures are being installed now (12).

4.05 The shorefast ice in the St. Marys River usually remains in place without moving until breakup. As a result, once a channel has been cut in the ice, ships are constrained to remain in it. The channel in ice is like a railroad track that keeps the ships in place. The most difficult time for navigation occurs during freezeup after the normal season buoys have been removed and before a fixed channel has been established in the ice (13).

4.06 Ships also use radar as an aid to navigation. Radar picks up the channel buoys easily and therefore radar can be used to follow the channel providing the buoys are in the water. Because of the narrow channels and sharp turns in the St. Marys River, radar is generally only used as a backup. This is particularly true for the large 1000 footers (9,10).

4.07 In 1978 an improved Loran-C was installed for navigation in the channel. Although the system is accurate enough to keep a ship in the channel, it has not been entirely successful because of reliability and calibration problems (7,10).

Control of Shipping

4.08 Traffic is always controlled in the St. Marys River, but it is more strictly controlled in the winter. Some sections of the channel have one-way traffic in winter, but because of the controls, there are no problems (9). Vessels report their estimated arrival time in the river and at transit points along the river by radio (11). Strict radio control prevents problems with one way traffic in the channel. Sections of the channel that have one way traffic are also identified in Notices to Mariners (10).

4.09 In heavy winter ice conditions, it is desirable to convoy ships through the channel (11). For example, three to five ships are gathered at Detour Passage and are led up the river by one or two icebreakers (12). The icebreaker escort reduces the possibility of ships having collisions with ice or navigation problems (9).

4.10 To improve safety in navigation, ships do not generally move in the channel at night during the winter (12). In addition, icebreakers do not generally break ice at night. But ships are not always restricted to daylight operations - it depends on the conditions (14). For example, when an icebreaker frees a ship stranded in ice, the ship is permitted to move at night rather than freeze in again (14). On the other hand, masters plan to navigate the channel in daylight whenever possible (9).

4.11 Mariners report that visibility is usually better in winter than in summer because there is no fog. In winter visibility may be restricted because of snow showers or blowing snow, but periods of restricted visibility are generally reduced. Although there is no strict rule for closing the river because of reduced visibility, whenever visibility is less than 1 mile, Coast Guard watch officers are concerned and follow weather conditions closely (15). A watch officer is sent to check visibility at critical points along the River, then a decision to close the River is made based on the observations at these locations. A decision to close the River may also be based on judgement of the pilots. If visibility is reduced to 1/2 mile or less, the River is likely to be closed. Using these guidelines, visibility conditions less than 1 mile are considered to be hazardous to navigation for the purposes of this study.

4.12 Figure III-3 shows the speed limits in the St. Marys River Channel. These limits remain in force both winter and summer; however, in the winter traffic moves much more slowly (9). Ice conditions slow ships down considerably. One reason for the slower speed is the prudence of the masters in moving in ice. Another reason is that the ships often use high power to push through ice rubble in the channel. This results in a slow speed of advance. In addition, if a ship pushing through ice has a mechanical problem or removes power because of a potentially dangerous situation, she stops immediately and remains in place in the ice. This fact essentially eliminates many of the hazards of navigation because the ship held in place in ice cannot collide with other objects or run aground. Although the ice presents some hazards to navigation, it also removes some others.

Ships's Officer Qualifications

4.13 Foreign ships moving in the Great Lakes are required to have a qualified pilot on board. U.S. ships have four pilots aboard - the master and three mates are all qualified pilots (13). Canadian tankers often take pilots when they are operating late in the year, although this is not required. Most U.S. and Canadian ships operating in the upper lakes make many trips through the St. Marys River every year and as a result, masters are highly qualified in piloting in these waters.

4.14 Crews of the tanker fleet are much more experienced in operating in ice than the bulker crews (7). Since the demand for oil is high in winter, tankers are more likely to continue to operate in ice when the system is kept open. Because of this experience, tanker crews are cautious whenever they see ice. If ice is suspected to be in the area, they slow down and proceed cautiously. Since tanker crews are more proficient in winter navigation, tankers are judged to have a lower probability of having an accident in ice then other ships (7).

Ice Conditions

4.15 Records of ice conditions for Lake Superior, Whitefish Bay, and the St. Marys River for the years 1972 to 1979 show a wide range of differences in ice cover between seasons (16). For example, ice cover on Lake Superior varied from 30% in 1974-75 to 100% in 1978-79. In that same period the first ice on Whitefish Bay was reported on 12 December 1976, but two seasons earlier, there was no ice on Whitefish Bay until 19 January 1975.

4.16 In spring ice begins to deteriorate in Lake Superior first. This ice is often driven by winds and currents into Whitefish Bay, which clears later. The last ice was reported on Whitefish Bay in mid-April in 1973 and 1976, but ice remained until the first week in May in 1974, 1978, and 1979.

4.17 The first ice was reported in the St. Marys River in mid-November in 1972 and during the first week in December in 1973 and 1974. Breakup began in the second week in March in 1973 and the River was ice free in mid-April; however, in 1974 breakup did not begin until early April and the River was not ice-free until 1 May. (A description of ice conditions in the St. Marys River is only available for 1972 through 1976.)

4.18 Whitefish Bay has a special problem with ice because prevailing winds and currents drive ice into the Bay out of Lake Superior (10). This ice rafts and forms pressure ridges which results in a considerable vertical development of ice. These heavy ice formations can be a threat to the safety of ships entering the area. Another problem with the ice in Whitefish Bay is that it does not remain in place. Because of the drifting ice, channels cut through Whitefish Bay may not remain in place and they may also be blocked by drifting ice.

4.19 The St. Marys River generally has stable, shorefast ice that is unlikely to shift. When channels are cut in the ice, they stay in place (9). There are generally no vertical developments of ice formed by ridging or rafting as in Whitefish Bay. The ice in the St. Marys River tends to be flat and smooth (9).

4.20 Ship traffic in the St. Marys River does not tend to build up piles of ice along the edge of the channel. Normally the ice that is broken along the side of the track flows downstream and out of the River (10). Icebreakers cutting the channel push the ice down and out; the ice goes under water and emerges astern or under the solid ice at the edge of the channel. The ice rubble left astern of the icebreaker is flooded with water and refreezes (10). This tends to build up thicker ice in the channel. The ice formed from rubble in the channel may grow to a thickness of 2 to 3 feet while the shorefast ice along the edge of the channel is about 18 inches thick.

4.21 Although the ice is stable along the channel in the St. Marys River, a ship's wake may crack the ice along the edge. This ice may be carried by winds and currents into the channel where it can freeze in and block the channel (10).

Ship's Characteristics

4.22 All bulk carrying lakers are double hulled, therefore there is not much chance of an oil spill resulting from a collision (10,13). In addition, collisions are generally in the bow and the fuel tanks for the bulkers are aft and inboard. This reduces the possibility of a spill in a collision. Also, vessels transiting the St. Marys River generally have only a few feet clearance with the bottom of the river. A ship holed as a result of a collision will not sink far. It will rest on the bottom of the river only a few feet below its normal draft so that additional damage is not likely to occur. Fuel tanks are not likely to be ruptured and the probability of a spill is low.

4.23 The probability of a vessel being damaged by a collision with the ice depends on the individual vessel. If the vessel has an ice reinforced bow, there should be no damage (12). Ships moving in ice should be ballasted so that their heavier plating is along the ice line to prevent ice damage to the hull. Screw and rudder damage are more common in accidents in the ice. Rudders are often damaged by being jammed with ice.

4.24 Low powered ships have a problem being beset in ice, however, newer high powered ships are not likely to have this problem. A ship with a horsepower to length ratio of 6/1 should not have problems getting through the ice (9). High powered ships are more likely to have problems swinging around corners in the ice. The 1000 footers have a lot of power, but the twisting motion in making turns is difficult. Because tankers are much smaller than other lakers, they do not have these maneuvering problems. Tankers are shorter, have less beam, and draw less water than other lakers, and therefore they are much easier to maneuver in ice-covered channels. This improved maneuverability also makes them less likely to have an accident (17). Table IV-1 shows a profile of Great Lakes tankers. Note that the average length of tankers, even those built in the last 10 years, is less than 400 feet. The large ore ships generally have a length in the 650 to 1,000 foot range. Also note that the tankers have an average draft of less than 22 feet. This means that the tankers are less likely to go aground.

4.25 Records of transits through the Soo Locks for fiscal year 1978 show that 82% of the tanker traffic in the area is Canadian. These ships are generally much newer than the American tankers and a great many Canadian tankers have been ice strengthened. These ships are often used along the Atlantic coast off season in harbors that usually have ice. These ice strengthened ships are less likely to have a spill if they do collide with ice.

Accident/Spill Potential

4.26 Accidents are not likely to happen in the St. Marys River in winter ice conditions (9). The most difficult turns in the channel are closed. Ships go slower and move along a fixed track and the ice prevents them from going out of the channel. In addition, ships have to use high power to push through the ice rubble that is in the channel. If a ship has a mechanical problem or some other emergency and cuts power, she will stop immediately and stay in place. There is no danger of drifting out of the channel and going aground (7). This is actually better than the situation that exists in the summer. If a ship has a problem in a summer fog and cuts power, the swift currents will continue to carry the ship along, either down the channel or out of it. There may be no way to stop if a safe anchorage cannot be found. Thus, the constraining force of the ice in the winter can help to prevent accidents as well as cause them.

TABLE IV-1 PROFILE OF GREAT LAKES TANKERS (18)

NATIONALITY	NUMBER OF SHIPS	AVERAGE AGE	STANDARD DEVIATION	AVERAGE LENGTH (ft)	STANDARD DEVIATION	MID-SUMMER DRAFT (ft)	STANDARD DEVIATION	AVERAGE CAPACITY (Long Tons)	STANDARD DEVIATION
U.S.	13	27	22	254	160	16	6	6,376	3,041
CANADIAN	35	17	10	395	94	22.5	5	10,188	4,371
TOTAL	48								
U.S. & CANADIAN BUILT IN LAST 10 YRS	13 (5 U.S, 8 CAN)			380	108	21.5	5	10,707	2,870

4.27 Most experienced operators in the St. Marys River have not seen a problem of ships colliding with the edge of the ice (10). Ships are more likely to move along the edge of the ice to stay in the channel than collide with it. The total number of vessel transits is greatly reduced in the winter, therefore the danger of collision is also reduced. Tankers do move late in the season to meet the winter demand for fuel, but there is not necessarily an increased number of tankers transiting the river. Tanker traffic can be expected to remain about the same in winter (12).

General Operational Assessment

4.28 The general assessment of Coast Guard officers who are responsible for the safe navigation in the St. Marys River Whitefish Bay area is that the threat of a disastrous collision decreases in ice. "The presence of ice stops a ship's movement, therefore prevents the collision" (12). Captain Gordon Hall, USCG, Chief of Operations, 9th Coast Guard District, Cleveland, Ohio, sums up this assessment by stating that "the casualty incident rate would not be greater in the winter than in the summer".

V. SPILL POTENTIAL BASED ON SHIP'S STRUCTURAL DESIGN

5.01 There have been no spills resulting from ship accidents in the St. Marys River or Whitefish Bay since the Coast Guard began to keep separate spill records in 1974. Because records of spills from accidents are not available, this section investigates the potential for a spill resulting from an accident based on the structural design of ships used in the Great Lakes.

Spill Potential Based on Hull Configuration

5.02 Figure V-1 shows a sketch of the fuel tank configuration on a typical Great Lakes bulker. Note that the tanks are located well aft and about 4 to 6 feet inside the hull shell. An oil spill resulting from a grounding is unlikely because the ship has a double bottom and fuel tanks are protected from damage by the engine room. For a spill to occur, the ship would have to be rammed in the 60 to 70 foot section that contains a fuel tank with damage extending through the hull shell, the 4 to 6 foot void, and the fuel tank. Bulkers usually have port and starboard fuel tanks with a full capacity of 50,000 gallons each.

5.03 All new tankers and tank barges have double hulls. These ships are constructed with a void tank and cofferdam in the bow so that a collision right at the bow is not likely to result in a spill. Although newer tankships are protected by double bottoms and ballast wing tanks, a spill could result from damage to the hull caused by ice crushing, grounding, or collision in the midship section of the vessel. The full capacity of one starboard or port fuel tank is about 200,000 gallons for a new tank barge. A grounding that results in severe damage to the hull could empty the entire tank. A collision that ruptures the hull at the waterline could cause a spill of about 22,000 gallons. Older tankships do not have double hulls and therefore are more likely to have a spill resulting from an accident.

Spill Potential Based on Hull Strength

5.04 Great Lakes ships are not generally built to American Bureau of Shipping (ABS) ice class specifications because no definite correlation between ice classification and resistance to ice damage has been formulated. Ice strengthening of a Great Lakes vessel usually occurs only on the bow between the

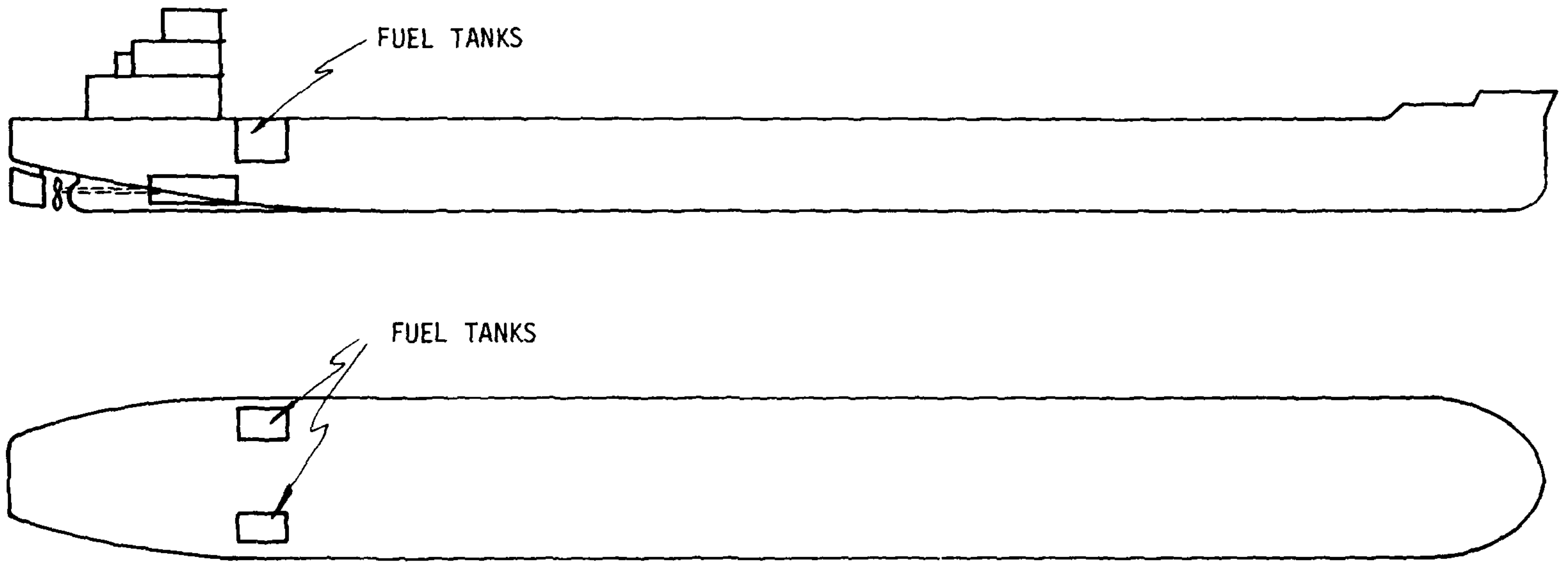


FIGURE V-1 FUEL TANK CONFIGURATION, TYPICAL GREAT LAKES BULKER light and loaded waterlines (19). This procedure is followed because while a ship is underway, most collisions occur in the bow.

5.05 Ship collisions with ice frequently occur during extended season operations. Table VI-14 shows that of the ten collisions with ice that occurred between 1974 and 1979, five occurred in Whitefish Bay, three occurred near Gros Cap Reef at the entrance to Whitefish Bay, and two occurred in the St. Marys River. In many cases these collisions with ice only result in propeller and rudder damage; however, if a ship is disabled because of propeller or rudder damage, it could also be subject to crushing force from ice by drifting into ice pieces. This crushing force may cause plastic deformation or even rupture of the hull plates of the ship.

5.06 Table V-1 shows the estimated uniform ice pressure required to cause plastic deformation of a hull plate for a Great Lakes vessel. The crushing strength of fresh water ice can be up to four times that of salt water ice. The crushing strength of warm sea ice is 210 pounds per square inch (psi). The uniform ice pressures required for plastic failure of hull plate shown on Table V-1 are therefore small as compared to possible fresh water crushing strengths of 210 to 840 psi. It should be emphasized that Table V-1 shows the <u>uniform</u> ice pressures that are required for plastic deformation. The crushing force of a long sheet of ice or pile of ice rubble is often non-uniform. A major portion of the section of hull plate would have to be subject to the crushing force for failure to occur. Thus, failure is not as likely as may seem to be indicated by the ice pressures required for plastic deformation shown in Table V-1. For a given set of ice conditions, a finite element analysis is required to determine the exact location and extent of damage to the hull plating of a vessel. Traditionally, most ice damage analysis is performed after the damage has occurred. The ice pressures presented here are intended to be rough estimates of the forces required to cause hull damage.

5.07 The worst ice loading situation is one in which the ship is drifting or swinging at a mooring against a large, landbound flow of ice. The crushing strength of the ice varies with the strain rate. Strain rate is equal to the ship's velocity divided by the diameter (length) of the ice floe. Figure V-2 shows the relationship between the crushing strength and strain rate of unconsolidated sea-ice. The strain rate would correspond to the brittle portion of the curve. This corresponds

TABLE V-1 ESTIMATION OF UNIFORM ICE PRESSURE REQUIRED TO CAUSE PLASTIC DEFORMATION OF HULL PLATE GREAT LAKES VESSEL

VESSEL	STEEL 1	HULL PLATE THICKNESS (in.)	FRAME SPACING (ft)	UNIFORM ICE PRESSURE REQ'D FOR PLASTIC FAILURE OF HULL PLATE 2 (psi)	ICE STRENGTHENING
Bulk Carrier (1) Δ 38,560 L.T. Summer Draft 27'6" LOA 730'0"	ABS HTS Gr. A H36 σ_y - 51,000 psi	9/16	7.5	7.97 (8.02) = 64	Bow
Tank Barge (2) Summer Draft 22'2" LOA 431'0"	ABS MS Gr. A σ_y - 34,000 psi	9/16 1/2	8.0 8.0	4.67 (7.31) = 34.1 3.69 (7.91) = 29.2	Increase in hull plate thickness from 1/2 to 9/16

1. The types of steel used for the construction of ships navigating in ice worldwide, are described in Appendix C-3, Ref 19. The American Bureau of Shipping (ABS) specifies a group of low strength steels (MS) and higher strength heat treated steels (HTS) suitable for navigation in ice. A group of high strength low temperature steels are required for icebreaking vessels.

2. The uniform ice pressure required to produce three plastic hinges (one at each support and one at the center of the plate) allowing for membrane effects of the plate (Appendix D, Ref. 19).

$$P = \left\{ 4\,\sigma_y \left(\frac{t}{s}\right)^2 \right\} \cdot \left\{ 2.28 \sqrt[3]{\frac{\sigma_y}{E} + \left(\frac{s}{t}\right)^2} \right\}$$

P = Maximum ice pressure allowable without onset of platic deformation (psi)
σ_y = Yield strength of the steel (psi)
t = Plate thickness (in)
s = Frame spacing (in)
E = Elastic modulus of steel (psi)

Membrane effects are changes in geometry of the hull plate between the two frame supports which allow for the absorption of additional loading. If the steel is thick with closely spaced framing, membrane effects will be negligible, and the pressure should be calculated according to:

$$P = 4\,\sigma_y \left(\frac{t}{s}\right)^2$$

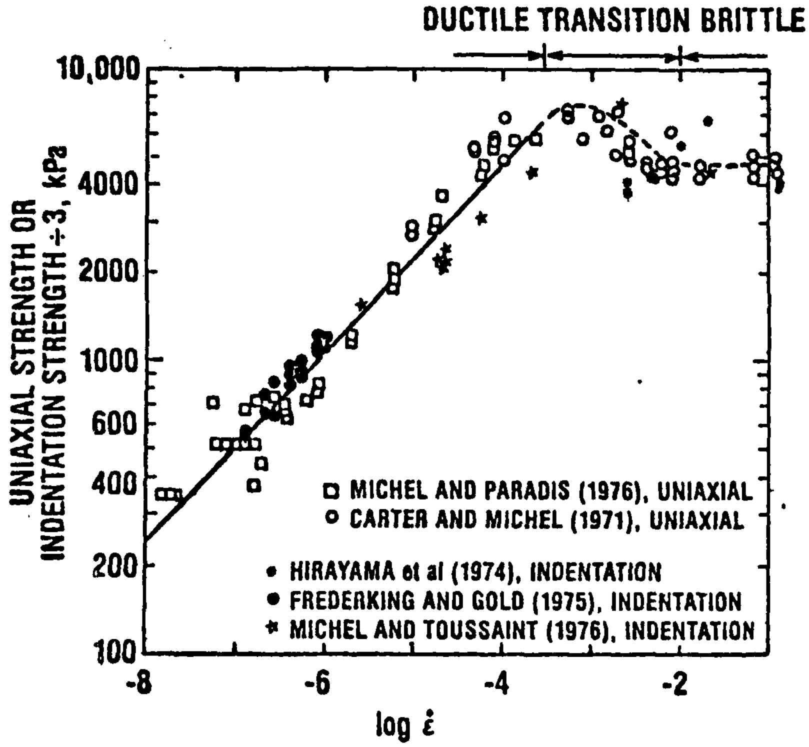


FIGURE V-2 UNCONSTRAINED CRUSHING STRENGTH OF SEA-ICE (BEAUFORT SEA) VS. STRAIN RATE to an unconstrained sea-ice crushing strength of 4700 kPa or 680 psi. The constrained crushing strength of ice is three times its unconstrained crushing strength. In this case the fresh water ice would be constrained against the side of the ship with a crushing strength of three to twelve times the unconstrained sea-ice crushing strength of 680 psi. Lakes ships should avoid at all costs situations in which they are drifting or swinging at anchor against large, landbound floes of ice. These situations are very likely to cause hull damage, but since fuel tanks are generally protected by a void space or a double hull, this damage would not necessarily cause a spill.

VI. VESSEL TRANSITS, ACCIDENTS, AND SPILLS

Vessel Transits Through the St. Marys River and Whitefish Bay

6.01 The St. Marys River is a choke point to shipping traffic between Lake Superior and the lower Great Lakes. Ports of Lake Superior are the primary source of cargoes - iron ore, wheat, and coal -that are transported to ports in the lower Lakes and in some cases overseas. There are some ports in the St. Marys River area, but the primary function of this waterway is to provide an avenue for the flow of traffic from one location to another. Because of this characteristic, the standard measure of vessel activity in the area is the transit or passage of a vessel between Lake Superior and Lake Huron. Collecting data for this analysis, then begins with a tabulation of vessel transits through the St. Marys River and the Soo Locks.

6.02 Table VI-1 shows the transits through the Soo Locks for the period 1974 through 1979 (20). These figures include transits of passenger and dry cargo vessels, tankers, towboats and tugboats, dry cargo barges, and tanker barges. The categories of yachts, sail boats, and workboats are not included because these vessels do not have the potential to cause a large oil spill. Although towboats and tugboats are generally omitted from statistics relating to cargoes passing through the Soo, they are included here because they are considered to present an important threat to oil spills. Tankers and tank barges are shown separately because they are the most significant threat to a spill and these transit numbers are used later in the analysis.

6.03 Total annual transits provide an important statistic for this analysis, however it is also necessary to review seasonal transit levels. Figure VI-1 shows the average monthly transits for the period of this analysis. The Season Extension Demonstration Program was in operation during this time so that the Soo Locks were open for all but about two and a half months of the period of this report. Figure VI-1 shows that shipping activity reaches a peak in July. From this high point, transits fall off gradually through December and reach the lowest level during the heaviest ice months of February and March. Although the navigation season traditionally begins in April, April is still a month of ice and transits are generally low.

TABLE VI-1 SOO LOCKS VESSEL TRANSITS, 1974-1979 (18)

YEAR	1974		1975		1976		1977		1978		1979	
MONTH	TOTAL	TANKERS (BARGES)	TOTAL	TANKERS (BARGES)	TOTAL	TANKERS (BARGES)	TOTAL	TANKERS (BARGES)	TOTAL	TANKERS (BARGES)	TOTAL	TANKERS (BARGES)
JANUARY	138	0(2)	228	8	146	3	73*	0	189	18	165	20
FEBRUARY	10[3]	0	71	1	46	0	4	4[5]	64	8	35	6
MARCH	CLOSED	CLOSED	103	0	31	0	19	3	65	10	29	11
APRIL	563*[4]	12(2)	615	24	602	12	571*	11*	571	28	448	21
MAY	1235	28(2)	1146	22	1074	19(1)	1118*	35*	1230	33	1200	40
JUNE	1554	15(4)	1424	28(1)	1302	26	1426*	29*	1514	39	1514	46
JULY	1933	22(2)	1720	26(2)	1766	23	1903	52	1903	52	1856	27
AUGUST	1724	10(2)	1601	17(1)	1728	17	1402*	15*	1833	27	1740	33(2)
SEPTEMBER	1384	18	1426	17	1476	21	1043*	38*	1529	34	1472	30
OCTOBER	1283	31	1063	23	1153	33	784*	37*	1229	35	1294	46
NOVEMBER	1116	36	827	23	898*	35	666*	33*	1108	39	1074	46
DECEMBER	775	15(3)	712	20	542	18	617	29	834	32	740	31
TOTALS	11,715	204	10,936	213	10,764	208	9,626	286	12,069	355	11,567	359

TOTAL TRANSITS 1974-1979	66,677
TANK SHIP TRANSITS	1,625

NOTES: (1) Total transits include the following classes of vessels: (a) passenger and dry cargo, (b) tanker, (c) towboat and tugboat, (d) dry cargo barge, (e) tanker barge. The categories of yacht, sail, and workboats are not included.

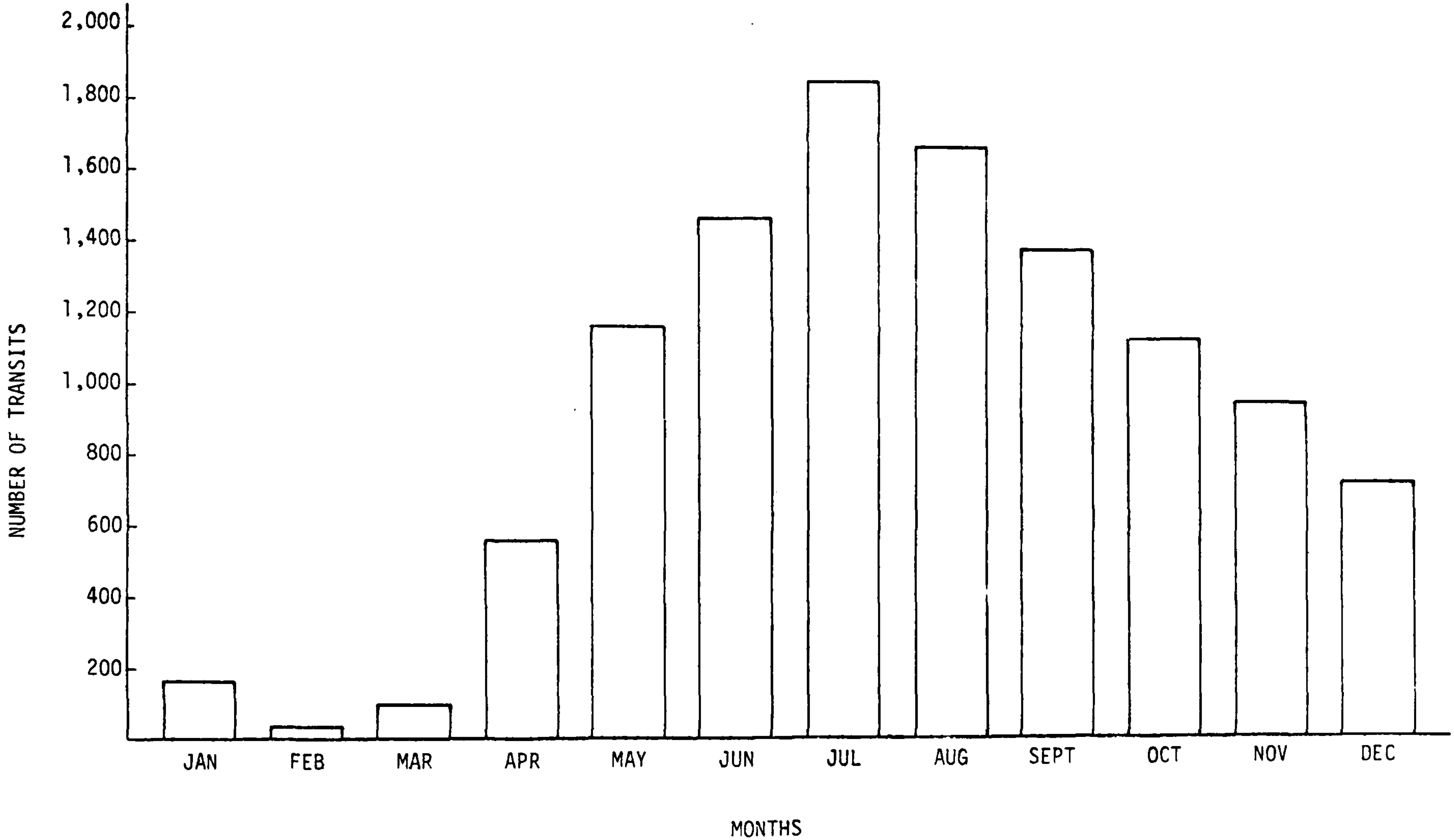
(2) The asterisk (*) indicates estimated data. Records of transits according to vessel type are not available for some monthly periods, however total transits including the category of yachts, sail, and workboats are available in every case. For those months in which data are lacking, estimates of transits less yachts, etc. are based on an average percent reduction of the total transits including all vessel categories. The appropriate percentage reductions are averages obtained from the months in which complete data are available. To estimate tanker transits, the volume of petroleum products going through the Soo each month is divided by the average tanker load for that month. Using known data, these estimates can be shown to be accurate to within 0 to 2 transits per month.

(3) Locks closed 2/7/74.

(4) Locks opened 4/2/74.

(5) Locks closed 2/24/77 to 3/17/77

FIGURE VI-1 AVERAGE MONTHLY TRANSITS, 1974-1979



6.04 Next consider tanker transits alone since this shipping activity presents the greatest danger of a large oil spill. Figure VI-2 shows the average number of tanker transits by month for the period of the analysis. As in the case of total transits, tanker transits tend to be low in winter and build to a maximum in July. Tanker activity is different, however, in that there is a sharp drop in transits in August followed by another high point in November. This occurs because the tankers are supplying fuel oil to the cities along Lake Superior. Late season activity shows suppliers building fuel stocks for the winter. In fact, tanker transits remain relatively high in December and, as compared to total transits, they stay fairly high through the remaining winter months. This is because the demand for fuel remains high during the winter and if the Locks remain open and passable, the tankers are likely to continue to run. If additional fuel cannot be brought into the area by tankers in the winter, it often must come in by rail. Transportation costs for rail shipment are about three times the cost of water transport, so that the motivation for running tankers late in the season is high (17).

6.05 Figure VI-3 compares total annual transits with total tanker transits for the period 1974 through 1979. This graph shows that tanker transits tend to be independent of the total transits. For example, in both 1975 and 1977 total transits are declining, but tanker transits are increasing. This can be explained in terms of the kinds of products that are carried. Most transits through the Soo Locks are for bulk commodities such as ore, coal, or grain. (Only 2.4% of the transits during this period were tankers.) The demand for the bulk commodities is entirely independent of the demand for petroleum products. Total transits through the Locks are tied to the requirement for ore for the steel industry and to a lesser extent the demand for grain overseas. Tanker transits, on the other hand, depend on the local demand for fuel oil and gasoline. This demand depends on winter temperatures in the area and the consumption habits of the residents along the shores of Lake Superior.

6.06 If the Locks are open for an extended season, there are likely to be more tanker transits because winter deliveries of fuel by ship are much cheaper than deliveries by rail. However, from 1975 to 1979 when the Locks were open nearly continuously, there was not a uniformly high level of tanker activity. Demand for petroleum products appears to be more important in determining the number of tanker transits than the

FUGURE VI-2 AVERAGE MONTHLY TANKER TRANSITS, 1974-1979

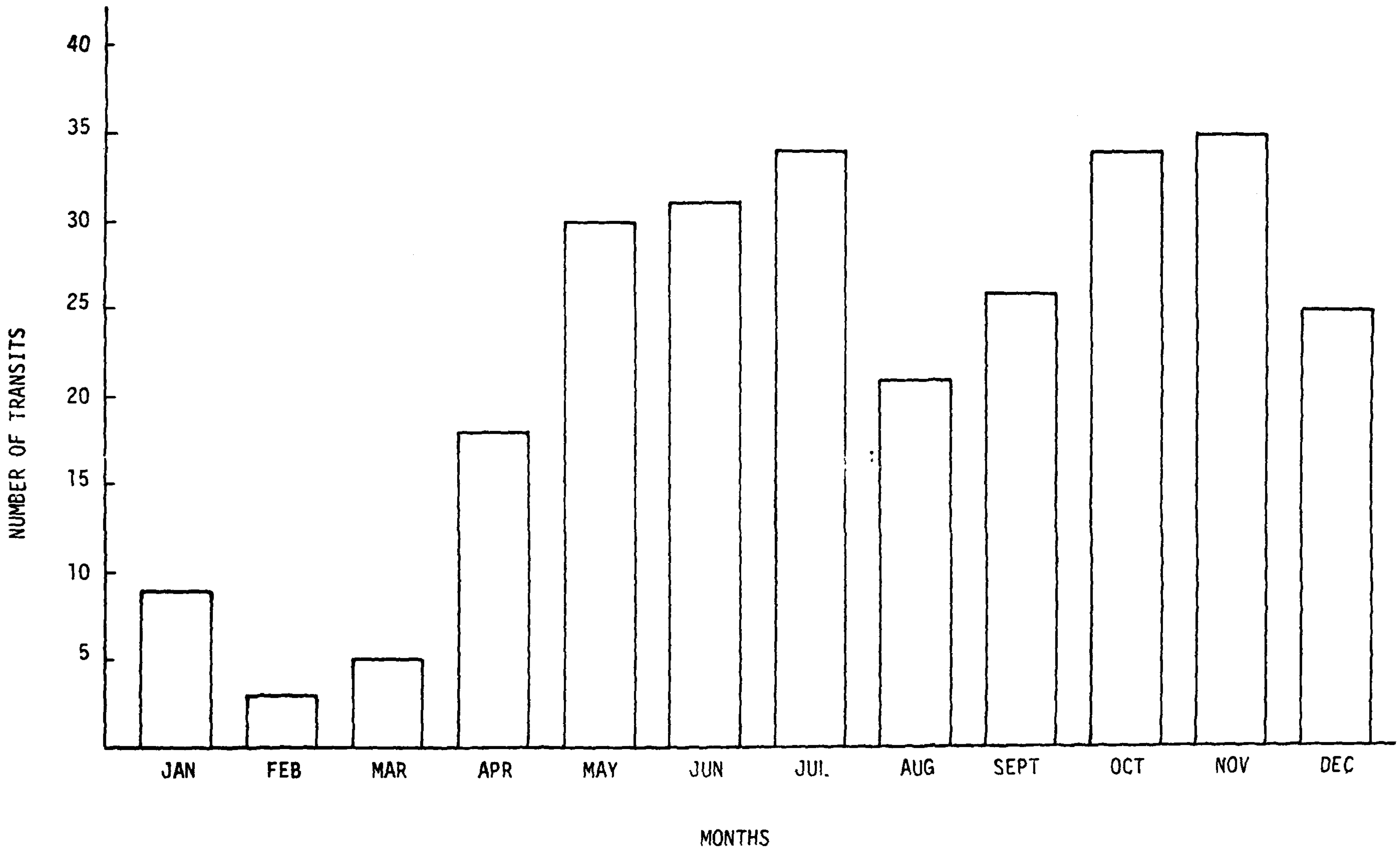
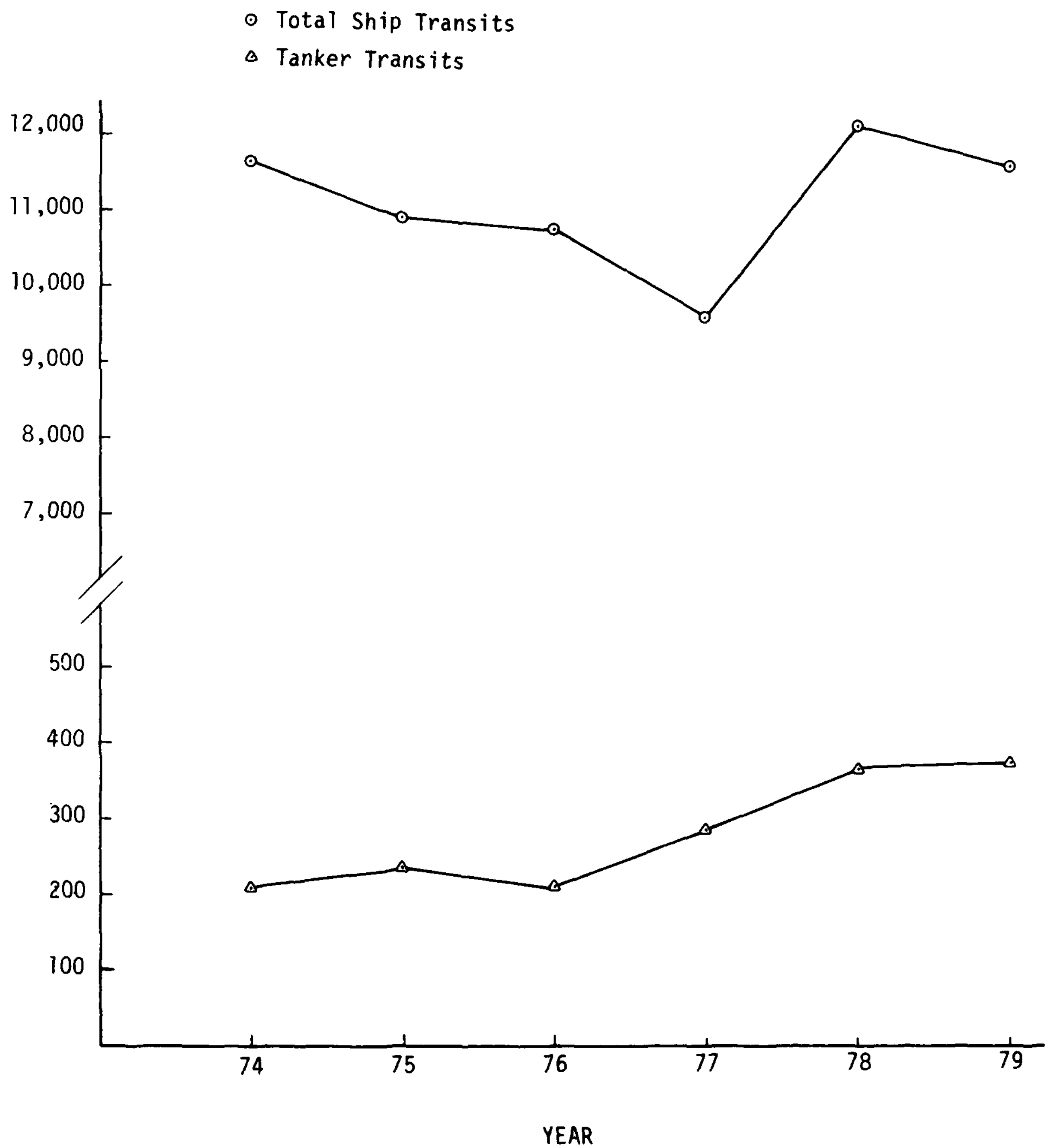


FIGURE VI-3 TOTAL SHIP TRANSITS AND TANKER TRANSITS, 1974-1979



length of season. This demand is probably closely linked to seasonal weather. Other factors affecting demand may include population shifts, industry shifts, and energy consumption or conservation habits of the population. Because of these relationships, future tanker transits cannot be forecast based on the trends of all traffic transitting through the Locks. Tanker transits can only be linked to demand for petroleum products, and this demand has been in a state of change during the past few years.

6.07 The nature of the petroleum shipping business can also be illustrated by the kinds of products that are carried and the size of ship that is used in this trade. Table VI-2 shows a petroleum product summary for fiscal year 1978. This year is typical of season in which a high volume of products were shipped.

6.08 The first part of Table VI-2 shows that fuel oil is the principal product shipped. This is followed by gasoline and a miscellaneous category, which includes some shipments of Number 6 fuel oil, but no crude oil. This is significant in that it shows that the traffic is entirely refined products based on consumer requirements in the Lake Superior area.

6.09 Next note that the tankers are small ships with an average load of less than 8,000 tons. This is a sharp contrast with the "1000 footer" ore carriers that may have a load carrying capacity of more than 60,000 tons. In addition, the average draft of tankships is about 20 feet, which means they are less likely to go aground in restricted waters than the larger ships that typically draw 26 to 27 feet of water. The average size tanker navigating the St. Marys River in 1978 compares favorably with the profile of Great Lakes tankers given in Table IV-1.

6.10 Table VI-2 also shows that almost 82% of the 1978 tanker traffic is Canadian. This is significant in that the Canadian tankers are generally newer than their American counterparts and most often they have ice-strengthened bows and double hulls. These ships are less likely to have a spill as a result of an accident than the older U.S. ships. Also, only a small percentage of tanker traffic in the St. Marys River is foreign. Therefore tanker casualty rates should not be affected by the higher accident rates experienced by foreign ships operating in the Great Lakes. Note that Table VI-2 shows shipping activity in terms of tanker loads. The tankers are generally full on

TABLE VI-2 PETROLEUM PRODUCT SUMMARY FY 1978

SUMMARY ACCORDING TO FUEL TYPE
(Some tankers carry more than one type fuel)

NUMBER OF LOADS	PRODUCT	AVERAGE TONS/LOAD	STANDARD DEVIATION TONS/LOAD	TOTAL TONS	% OF TOTAL PRODUCTS HAULED
68	Fuel Oil	6,177	2,587	420,012	53%
47	Gasoline	4,412	3,020	207,369	26%
25	Misc.	6,876	2,217	171,893	21%
				799,274	100%

SUMMARY OF FULL SHIP LOADS

NUMBER OF SHIPS	AVERAGE TONNAGE	STANDARD DEVIATION OF TONNAGE	AVERAGE DRAFT	STANDARD DEVIATION OF DRAFT	TOTAL TONNAGE
109*	7,333	2,443	20.1 ft	2.8	799,274

SUMMARY OF SHIPS ACCORDING TO NATIONAL ORIGIN

ORIGIN	LOADS	%
Canadian	145	81.9
U.S.	31	17.5
Norway	1	.6
	177*	100 %

* Ship's load not reported for all transits.

the trip up and in ballast on the trip back, so that 177 loads corresponds to about 354 transits.

6.11 Table VI-3 shows petroleum products transported in the St. Marys River according to product type. Note that crude oil is not transported through the St. Marys River at all; all cargoes are refined petroleum products. Also note that the ligher refined products such as gasoline and distillate fuel oil make up nearly 76% of the total traffic. The heavier residual fuel oil and low grade products such as asphalt are a much smaller percentage of the total cargoes.

6.12 Later in this analysis accident rates are computed for good visibility conditions and for low visibility conditions. It is therefore necessary to estimate the number of transits that have occurred in these conditions. Table VI-4 shows the percent of the time that low visibility occurred in the St. Marys River during the period of this study (22). Although there is no exact definition of low visibility, for this study, visibility of less than one mile is considered to be low. This assumption is based on an interview with the Captain of the Port at Sault Ste. Marie (15). The estimated number of transits that occurred in low visibility is determined by multiplying the number of transits in Table VI-1 by the percent low visibility conditions that occurred in each month. All remaining transits are assumed to occur in good visibility. The results are shown on Table VI-5.

6.13 In the process of gathering tanker transit information for the St. Marys River, it was discovered that some Canadian tankers call at Sault Ste. Marie, Ontario without going through the Soo Locks. These transits are therefore not counted in the records obtained at the locks. To estimate the number of ships engaged in this trade, all of the petroleum shippers at Sault Ste. Marie, Ontario were contacted to get an estimate of the average number of tanker calls at that port. These estimates are shown on Table VI-6.

6.14 Finally, to perform the analysis, it was necessary to predict the number of tanker transits that would occur in the St. Marys River for the various season extension periods considered in this study. These estimates are shown on Table VI-7. These predictions are based on the average number of tanker transits that occurred during the Season Extension Demonstration Program and the expected future demand for petroleum products.

6.15 This completes the transit information that is needed for the accident analysis.

TABLE VI-3 DESCRIPTION OF PETROLEUM PRODUCTS TRANSPORTED THROUGH THE ST. MARYS RIVER (21)
1974-1977

(SHORT TONS)

YEAR / PRODUCT	1974		1975		1976		1977		PRODUCT TOTAL	% PRODUCT
	UP	DOWN	UP	DOWN	UP	DOWN	UP	DOWN		
GASOLINE	84,732	46,428	60,917	61,569	54,119	33,792	73,893	71,947	487,397	28
DISTILLATE FUEL OIL	224,856	12,114	206,860	2,739	208,716	---	174,776	---	830,061	47.7
RESIDUAL FUEL OIL (#6 OR BUNKER "C")	10,606	12,718	66,810	---	70,224	---	23,686	38,084	222,128	12.8
COKE, PET ASPHALTS, SOLVENTS	31,918	12,287	31,241	17,408	33,431	46,170	---	27,801	200,256	11.5
TOTAL ANNUAL TRAFFIC	352,112	83,547	365,828	81,716	366,490	79,962	272,355	137,832		
TOTAL, UP AND DOWN	435,659		447,544		446,452		410,187		1,739,842	100

TABLE VI-4 LOW VISIBILITY CONDITIONS IN THE ST. MARYS RIVER (21)
% TIME VISIBILITY IS ≤ 1 MILE

	YEAR						
MONTH	1974	1975	1976	1977	1978	1979	AVERAGE
JAN.	8.9	7.7	10.5	11.3	15.7	9.3	10.6
FEB.	7.1	11.6	8.2	4.5	2.2	5.8	6.6
MAR.	7.7	6.1	13.3	8.9	5.7	8.9	8.4
APR.	2.9	1.7	3.8	5.0	2.5	7.9	4.0
MAY	4.0	4.0	1.6	1.2	5.2	3.2	3.2
JUNE	2.9	4.2	1.7	2.9	5.4	4.2	3.6
JULY	5.2	1.6	0.8	5.2	4.4	2.8	3.3
AUG.	2.8	3.6	2.0	2.8	6.5	10.1	4.6
SEPT.	2.9	3.3	0.4	5.4	3.3	5.8	3.5
OCT.	6.9	1.6	2.4	6.1	0.8	4.8	3.8
NOV.	10.0	10.4	7.5	15.4	5.4	6.3	9.2
DEC.	6.1	5.7	6.5	8.5	12.5	10.1	8.2
AVG.	5.6	5.1	4.9	6.4	5.8	6.6	5.8

TABLE VI-5 LOW VISIBILITY/GOOD VISIBILITY TRANSITS, SOO LOCKS 1974-1979
Low visibility is ≤ 1 mile. Number of low visibility transits based on historical records shown in Table VI-4.

YEAR	1974		1975		1976		1977		1978		1979	
MONTH	GOOD VIS	LOW VIS	GOOD VIS	LOW VIS	GOOD VIS	LOW VIS	GOOD VIS	LOW VIS	GOOD VIS	LOW VIS	GOOD VIS	LOW VIS
JAN	126	12	210	18	131	15	65	8	159	30	150	15
FEB	9	1	63	8	42	4	4	0	63	1	33	2
MAR	0	0	97	6	27	4	17	2	61	4	26	3
APR	547	16	605	10	579	23	542	29	557	14	413	35
MAY	1186	49	1100	46	1056	17	1105	13	1166	64	1162	38
JUNE	1509	45	1364	60	1280	22	1385	41	1432	82	1450	64
JULY	1832	101	1692	28	1752	14	1804	99	1819	84	1804	52
AUG	1676	48	1543	58	1693	35	1363	39	1714	119	1564	176
SEPT	1344	40	1379	47	1470	6	981	56	1479	50	1387	85
OCT	1194	89	1046	17	1125	28	736	48	1219	10	1232	62
NOV	1004	112	741	86	831	67	563	103	1048	60	1006	68
DEC	728	47	671	41	507	35	565	52	730	104	665	75
TOTALS	11,155	560	10,511	425	10,494	270	9,136	490	11,447	622	10,892	675

TOTAL TRANSITS, 1974-1979

GOOD VISIBILITY	63,635
LOW VISIBILITY	3,042

TRANSITS IN ICE CONDITIONS 1974-1979

GOOD VISIBILITY	4,677
LOW VISIBILITY	400
	5,077

AVERAGE ICE CONDITIONS, 1974-1979

January	100% ice
February	100% ice
March	100% ice
April	73% ice
May	ice-free
December	13% ice

TABLE VI-6 ESTIMATE OF ST. MARYS RIVER TANKER TRANSITS THAT DO NOT CONTINUE TO THE SOO LOCKS
This table is based on shippers estimates of the number of tankers that visit Sault Ste. Marie, Ontario annually.

SHIPPER	PRODUCT	AVERAGE LOAD (BBL) PER TRANSIT	NUMBER OF PASSAGES	NUMBER OF LOADED TRANSITS	TOTAL PRODUCT CARRIED (BBLx1000)
AMOCO	Gasoline, light oil	60,000	14	7	420
BRANCH LINES	Gasoline, #2 & #6 fuel, diesel	62,000	10	5	310
GULF	Gasoline, #2 fuel, diesel	65,000	24	12	780
SHELL	Gasoline, #2 fuel, diesel	50,000	20	10	500
SUNOCO (HALCO TRANSPORT)	Gasoline, light oil	50,000	16	8	400
TEXACO	Gasoline, #2 & #6 fuel, diesel	60,000	28	14	840
TOTALS			112	56	3,250

TABLE VI-7 TANKER TRANSITS DURING EXTENDED SEASON OPERATIONS

SEASON	NUMBER OF DAYS	NUMBER OF ADDITIONAL DAYS	ADDITIONAL TRANSITS	TRANSITS IN OPEN WATER		TRANSITS IN ICE	
				GOOD VIS	LOW VIS	GOOD VIS	LOW VIS
1 APRIL - 15 DEC (BASELINE)	259	0	0				
1 APRIL - 15 JAN	290	31	25	3	0	20	2
1 APR - 14 FEB	320	61	35	3	0	30	2
25 MARCH - 15 DEC	266	7	3	0	0	3	0
18 MARCH - 15 DEC	273	14	6	0	0	5	1
YEAR-ROUND	365	106	45	3	0	39	3

Vessel Accidents and Spills

Vessel Accidents

6.16 Data on vessel accidents used in this analysis are taken from U.S. Coast Guard casualty records (23). These casualty records tabulate many kinds of incidents. Some of these incidents are occurrences that can clearly be recognized as vessel "accidents", while others are material failures or equipment failures. Casualty data that are related to vessel accidents include the following:

- Grounding
- Collision
- Foundering
- Capsizing
- Flooding
- Heavy Weather Damage

6.17 A large number of casualty reports concern material failures that are related to vessel's structure, machinery, and associated engineering equipment. Most of these material failures are not "accidents" in the sense that they could be related to an oil spill or to the threat of a spill. Because of this, material failures are not included in the accident data used in this analysis.

6.18 To perform an analysis of the probability of a vessel accident and the the probability of a spill, it is necessary to establish categories of accidents that are clearly related to spills, and accidents that are related to the basic statistic of the St. Marys River Waterway, which is vessel transits. Groundings and collisions are accident categories that are related to spills, and also can be related to vessel transits. Further, these accidents can be related to the chief environmental cause of accidents; low visibility. Records show that more collisions and groundings occur in low visibility conditions, therefore these categories are expanded to include accidents that occur in good visibility and accidents that occur in low visibility. Since winter transits are of particular concern in this study, collisions with ice are included as a separate accident category. A category of groundings in ice is not included because groundings are assumed to occur with equal frequency in open water and in ice, although there is reason to believe that they may be less likely to occur in the St. Marys River in shorefast ice.

6.19 The other accident categories of explosion and fire, foundering, capsizing, flooding, and heavy weather damage are less frequently related to oil spills and generally unrelated to vessel transits in the St. Marys River. As a result, these categories of accidents are shown when data is available, but they are not used to compute the probability of an accident and the probability of a spill in the analysis.

6.20 Now consider the ship accidents that have occurred in the St. Marys River and Whitefish Bay during the period of this study. Table VI-8 tabulates these accidents according to type and according to whether they occurred in good visibility or in low visibility. Visibiliity is assumed to be a causative factor in accidents in which the visibility is less than 1 mile. All grounding accidents are counted whether or not any damage is reported. The category of collisions includes collisions with ships and collisions with other fixed objects. The vast majority of the collisions are with piers and aids to navigation such as channel buoys. Collision with ice is used to cover all ice-related accidents. If an accident is listed as a material failure caused by ice, the casualty is assumed to be rudder or propeller damage resulting from a collision with ice. Heavy weather damage includes physical damage to the ship caused by heavy weather and incidents related to heavy weather, such as barge breakaways. The environmental conditions that constitute heavy weather have not been defined, and since wind and sea conditions are not recorded for the St. Marys River area, heavy weather is not used to compute the probability of an accident and the probability of a spill.

6.21 Note that all of the accidents reported for the St. Marys River/Whitefish Bay area are for bulkers. There were no tanker or tank barge accidents in this area during the period 1974 to 1979. These years are used as the period of the report because spill data are not available for years prior to 1974 and accident data are not available for years more recent than 1979.

Vessel Spills

6.22 Table VI-9 shows the oil spills that have been reported from ships during the period of the analysis. First note that none of these spills resulted from a vessel accident such as a grounding or a collision. All of these incidents are operational spills, that is, they either occurred during a transfer of fuel or they occurred as a result of a malfunction of a fueling system. Operational spills also include personnel

TABLE VI-8 SHIP ACCIDENTS IN ST. MARYS RIVER AND WHITEFISH BAY, 1974-1979 (23)
ALL ACCIDENTS ARE FOR BULKERS

YEAR	GROUNDING GOOD VIS	GROUNDING LOW VIS	COLLISION GOOD VIS	COLLISION LOW VIS	COLLISION WITH ICE GOOD VIS	COLLISION WITH ICE LOW VIS	HEAVY WEATHER	ANNUAL TOTAL
1974	2	1	2	1	1	0	0	7
1975	7	0	5	0	0	1	2	15
1976	8	1	11	0	4	0	0	24
1977	1	1	6	0	2	0	0	10
1978	8	2	4	0	5	0	0	19
1979	1	0	15	0	3	0	0	19
TOTAL	27	5	43	1	15	1	2	94

TABLE VI-9 SPILLS FROM SHIPS, ST. MARYS RIVER AND WHITEFISH BAY, 1974-1979 (24)

YEAR	SHIP TYPE	LOCATION	PRODUCT	SIZE OF SPILL (gal)	AMOUNT RECOVERED (gal)
1974	None				
1975	Tanker [1]	Lime Island	Heavy Oil	5	
	Other Vessel	Six Mile Pt.	Diesel	100	95
	Other Vessel	S.Ste.Marie	Diesel	1	
1976	Coast Guard	Mid.Neebish	Waste Oil	50	
	Fishing Vessel	Sugar Island	Heavy Oil	200	
1977	Tanker [1]	Mission Pt.	Fuel Oil	Sheen	
	Coast Guard	Crab Is. Shoal	Diesel	500	
1979	Coast Guard	Island #2	Lub Oil	5	3
	Coast Guard	S.Ste.Marie	Waste Oil	1	
1980	Coast Guard	Mission Pt.	Diesel	25	24
	Cargo [2]	Hay Pt.	Diesel	Unknown	
			TOTALS	887	122

Average Spill Size - 81 gallons
Percent Recovered - 14%

SPILL SUMMARY ACCORDING TO SHIP TYPE

TYPE	NUMBER	AMOUNT (gal)
Tankers	2	5
Cargo	1	Unknown
Other	2	101
Coast Guard	5	581
Fishing	1	200

TOTAL 11 Ships

NOTES: (1) Operational spills, there were no tanker spills resulting from accidents in the St. Marys River between 1974-1979.
(2) Accident data for 1980 are not yet available.

errors and equipment failure such as a valve failure or leak, a failure of a fueling line, or a failure of a fuel tank. Because none of the spills in the St. Marys River area have been as a result of accidents, it is necessary to look at a larger area to determine the probability of a spill as a result of a vessel accident.

6.23 Note that all of the spills listed in Table VI-9 are relatively small. Since spills of less than 1,000 gallons are defined in the National Contingency Plan as "minor", all of these discharges can be considered as minor spills (25).The spill summary according to ship type shows that spills from cargo ships and tankers, which include the vast majority of ship passages in the area, are small in number and small in size. There have been only three operational spills from these ships in a six year period with a total reported spill volume of 5 gallons. Further, there have been no spills during this period that have been a result of a collision or a grounding.

6.24 Table VI-10 shows oil spills from sources other than ships in the St. Marys River and Whitefish Bay area. These spills are also generally small and over the period of this report there have only been about three per year.

6.25 Transport of Other Hazardous Substances. Annual cargo reports show that basic chemicals, chemical products, and chemical fertilizers are carried through the St. Marys River (21). Records also show that a calcium chloride solution is often carried through the locks. This product is commonly used to settle the dust on country roads. Calcium chloride is not listed as hazardous substance by the Environmental Protection Agency (26).

6.26 Tankship Accidents and Spills, All Great Lakes. There are no reported ship spills resulting from accidents in the St. Marys River or Whitefish Bay during the period of this report; therefore, in order to compute the probability of a spill it is necessary to analyze a larger population of data. Since the greatest threat of a large spill is from a tankship, this study determines the probability of a tankship spill given an accident has occurred for all the Great Lakes and then assumes that the probability of a spill resulting from an accident would be the same in the St. Marys River/Whitefish Bay area. Stated more simply, the assumption is that once an accident occurs, the probability a spill will result is not area dependent. The probability of an accident is, of course, area dependent and this study uses accident records for the St. Marys River.

TABLE VI-10 SPILLS FROM SOURCES OTHER THAN SHIPS
ST. MARYS RIVER AND WHITEFISH BAY, 1974-1979

YEAR	SOURCE	SPILL LOCATION	PRODUCT	SIZE OF SPILL (gal)	AMOUNT RECOVERED (gal)
1974	Unknown	Gros Gap Reef	Diesel	Unknown	
	Unknown	Nates Marina	Light Oil	1	
1975	Onshore Fueling	S.Ste.Marie	Diesel	7	7
	Bulk Cargo	S.Ste.Marie	Diesel	1	
	Unknown	Detour Passage	Diesel	Unknown	
	Unknown	Sugar Island		Unknown	
1976	Unknown	SE Neebish	Other Oil	20	
1977	Other	Island #3	Other Oil	20	15
	Unknown	S.Ste.Marie	Heavy Oil	100	
	Other	S.Ste.Marie	Diesel	100	
	Marine Facility	S.Ste.Marie	Hydraulic Oil	2	
1978	Other	S.Ste.Marie	Heavy Oil	Unknown	
	Single Pt. Mooring	Mission Pt.	Hydraulic Oil	3	
1979	Single Pt. Mooring	Mission Pt.	Hydraulic Oil	1	
	Single Pt. Mooring	Island #3	Hydraulic Oil	3	
	Unknown	Lime Island	Heavy Oil	10	
	Unknown	Detour Passage	Light Oil	5	
1980	Other	S.Ste.Marie	Waste Oil	1	
			TOTALS	274	22

Average Spill Size - 15 gallons
Percent Recovered - 8%

SPILL SUMMARY ACCORDING TO SOURCE

SOURCE	NUMBER	AMOUNT (gal)
Onshore Fueling	1	7
Bulk Cargo	1	1
Single Pt. Mooring	3	7
Marine Facility	1	2
Other	4	121
Unknown	8	136
SOURCES	18	274

6.27 Table VI-11 shows the tankship accidents that occurred in all of the Great Lakes during the period of this study. Most of the accidents are collisions, but it must be remembered that this category includes collisions with fixed objects such as piers. Table VI-12 shows the spills that resulted from these accidents. Although there were more collisions than any other kinds of accidents, the number of spills resulting from these accidents is just the same as the number of spills resulting from groundings. The size of the spills resulting from collisions was relatively small, but there were six tankship groundings that resulted in major spills. Without performing any additional analysis, it could be concluded that a tankship grounding is the principal threat to a major spill.

6.28 Table VI-13 shows the operational spills that occurred from tankships in all of the Great Lakes during the period of this report. These spills are generally related to handling petroleum products in loading and transfer operations. It is evident that there are many such spills, but that each spill is generally small. The number of spills could probably be decreased appreciably by taking steps to reduce equipment failures and personnel errors. The probability of a spill is not computed from these data because there is no record of the number of loading and transfer operations that have occurred. In addition, there is no numerical baseline that can be used to determine the probability of equipment failure or material fault. These figures do show, however, that over the six years represented, there have been an average of 38 operational spills per year resulting in an annual discharge of 3,740 gallons of fuel. Unless operational procedures or equipment reliability change, this rate of discharge can be expected to continue in future years.

6.29 Table VI-14 shows the locations of accidents that occurred in the St. Marys River and Whitefish Bay during the period covered by the study. The Table shows that groundings, which are the most dangerous accidents to large spills, can occur almost anywhere, although the frequency is somewhat higher in the Middle Neebish Channel and in Detour Passage. Although Detour Passage has no obvious threats to navigation, the Middle Neebish Cahnnel is marked by many sharp turns, and only half the channel is dredged to the project depth of 27 feet. The other half is considered the upbound channel for ships in ballast and is only dredged to 21 feet. Tankships, however, are loaded upbound and in ballast downbound, so that the 21 foot channel is a hazard to tanker groundings. Whitefish Bay is broad and very deep, therefore groundings are not likely to occur in this area.

TABLE VI-11 TANKSHIP ACCIDENTS, ALL GREAT LAKES, 1974-1979 (23)

YEAR	GROUNDING	COLLISION	FIRE EXPLOSION	FOUNDERING, CAPSIZING, FLOODING	HEAVY WEATHER
1974	13	12 3(Ice)	3	3	11
1975	3	28 2(Ice)	9	0	15
1976	11	29 1(Ice)	4	6	8
1977	22	30 3(Ice)	0	2	3
1978	18	35	4	10	2
1979	14	37	6	2	0
TOTALS	81	180 9(Ice)	26	23	39

Total of Tankship Accidents, 1974-1979 358

TABLE VI-12 TANKSHIP SPILLS RESULTING FROM ACCIDENTS, ALL GREAT LAKES, 1974-1979 (24)
Amount Spilled in Gallons

YEAR	GROUNDING		COLLISION		EXPLOSION/FIRE		FOUNDERING, CAPSIZING, FLOODING		HEAVY WEATHER	
	NUMBER	AMOUNT	NUMBER	AMOUNT	NUMBER	AMOUNT	NUMBER	AMOUNT	NUMBER	AMOUNT
1974	2[1]	152,000	0	0	0	0	0	0	0	0
1975	1[2]	73,000	1	10	0	0	0	0	0	0
1976	3[3]	426,005	5	172	0	0	0	0	0	0
1977	3[4]	20,300	2	70	0	0	0	0	3	28
1978	0	0	1	200	0	0	0	0	0	0
1979	0	0	0	0	0	0	1	200	0	0
TOTALS	9	671,305	9	452	0	0	1	200	3	28
GALLONS/ INCIDENT		74,589		50		0	200		9	

Total Spills from Accidents	22
Total Amount Spilled	671,985
Amount Spilled per Incident	30,545

NOTES:
(1) Tankship 147,000 gallons
(2) Tankship 73,000 gallons
(3) Tank barge 126,000 gallons
Tank barge 300,000 gallons
(4) Tank barge 10,000 gallons
Tank barge 10,000 gallons

SPILLS ACCORDING TO PRODUCT TYPE (GAL)

Light Crude	147,000	21.9%
Jet Fuel	5,000	.7%
Diesel	496	.07%
#5 Fuel	73,000	10.9%
#6 Fuel	436,010	64.9%
Gasoline	2	--
Chemicals	10,020	1.5%
Other	457	.07%
	671,985	100%

TABLE VI-13 OPERATIONAL SPILLS FROM TANK SHIPS
ALL GREAT LAKES, 1974-1979 (24)
Operational spills are generally those that occur during loading, offloading, and transfer. Spills that result from material failures and other causes are included in operational spills because they cannot be linked to accidents.

Amount Spilled in Gallons

YEAR	EQUIPMENT FAILURE		PERSONNEL ERROR		INTENTIONAL DISCHARGE		MATERIAL FAULT		OTHER	
	NUMBER	AMOUNT	NUMBER	AMOUNT	NUMBER	AMOUNT	NUMBER	AMOUNT	NUMBER	AMOUNT
1974	7	1,171	8	3,118	2	50	7	557	2	21
1975	11	373	5	420	0	0	3	161	4	278
1976	18	485	30	5,486	2	300	3	18	11	242
1977	10	257	17	873	0	0	0	0	11	1,515
1978	20	916	18	337	3	25	2	1	13	4,990
1979	7	187	6	415	2	35	3	270	4	47
TOTAL	73	3,389	84	10,649	9	410	18	1,007	45	7,093
Gallons/ Incident		46		127		46		56		158

Total Operational Spills	229
Total Amount Spilled	22,548 gallons
Amount Spilled per Incident	98 gallons

TABLE VI-14 ACCIDENT LOCATIONS, ST. MARYS RIVER AND WHITEFISH BAY, 1974-1979 (22)

GROUNDING

Gros Cap Reef, Whitefish Bay	2
Iroquois Shoal	2
Soo Locks	2
Lower Soo Harbor	1
Lake Nicolet	2
Middle Neebish Channel	5
Munuscong Channel	2
Frenchette Range	2
Johnsons Point	1
Sailors Encampment Range	1
Hay Point Range	1
Birch Point Range	1
Detour Passage	5

COLLISIONS

NAVIGATION AIDS

NEEBISH CHANNEL, BUOY 54
WEST NEEBISH CHANNEL LIGHT 32
CANADIAN BUOY 110
SOO HARBOR BUOY

SUBMERGED OBJECTS

Johnson Point
Poe Lock
Frying Pan Light

OTHER SHIPS

Soo Locks (2 mi. above)
Ship and Escort Icebreaker

LOCKS

25 cases

OTHER STRUCTURE

International Bridge Control House

PIERS

5 cases

ICE

Stribling Point	1
Whitefish Bay	5
St. Marys River	1
Gros Cap Reef	2
Gros Cap Light	1

6.30 Most collisions in the St. Marys River/Whitefish Bay area are with fixed objects. By far the most collisions are with the locks followed in number with collisions with ice (mostly in Whitefish Bay) and collisions with piers. Collisions are not as great a threat to spills, particulary not the collisions with fixed objects.

6.31 Table VI-15 shows tanker spills according to ship type for all of the Great Lakes. This Table shows that more spills occur from tank barges than tankships. This observation is not especially significant in that in recent years barges have been used more than ships. In the St. Marys River area this is not true, however. Table VI-1 shows a very low number of barge transits through the Soo Locks. The data on ship size and length simply reflect the size ships that are being used. The record of the age of ships shows that there is certainly no trend for the oldest ships to have the most accidents. Most spills have occurred from newer ships, but in the lower regions of the Great Lakes where there is a higher level of tanker traffic, fleet operators are probably using newer ships.

TABLE VI-15 TANKER SPILLS ACCORDING TO SHIP TYPE, ALL GREAT LAKES (24)

	NUMBER
SHIP TYPE	
Tankship	8
Tank Barge	13
Foreight Tank Ship	3
	24
SHIP SIZE - GROSS TONNAGE	
300-500	1
500-1,000	1
1,000-5,000	10
5,000-10,000	1
10,000-15,000	2
>15,000	9
LENGTH IN FEET	
100-100	3
200-300	9
300-400	1
400-500	1
500-600	1
600-700	5
>700	4
AGE YEARS	
<5	7
5-10	4
10-15	2
15-20	5
20-30	1
30-40	4
Unknown	1

VII. ASSESSMENT OF SPILL RISK

Method of Determining Spill Risk

7.01 A great many calculations are involved in determining the risk of a spill for this analysis, but the method is quite simple. The plan is to determine the probability of an accident and a spill for the normal navigation season, then use these results to determine the probability of an accident and spill in the various extended season alternatives based on the estimated number of transits that would occur in these seasons.

7.02 The basic variables used in making the computations are as follows:

P_A - probability that a ship has an accident

$P_{S/A}$ - probability of a spill, given an accident has occurred

P_S - probability of a spill

7.03 Probability of a Accident. The computational requirement is to determine the probability of an accident for a given number of extended season transits. Let N equal the number of transits and P_{Ai} the probability of an accident under different environmental conditions. It turns out that there are only two sets of environmental conditions that have been recorded and can be associated with vessel accidents in the St. Marys River: these are good visibility and low visibility. Assume that there are N transits in an extended season and that n_G transits occur in good visibilty and n_L transits occur in low visibility. $(N = n_G + n_L)$. Further, assume that P_{AG} is the probability that an accident occurs in good visibility and P_{AL} is the probability that an accident occurs in low visibility. Using these symbols, the probability that an accident does not occur in good visibility is $(1 - P_{AG})^{n_G}$ and the probability that an accident does not occur in low visibility is $(1 - P_{AL})^{n_L}$. The probability than an accident does not occur in both of these conditions is $(1 - P_{AG})^{n_G} (1 - P_{AL})^{n_L}$. The probability that an accident does occur in the first N transits where $N = n_G + n_L$ is therefore

(1) $P_A = 1 - (1 - P_{AG})^{n_G} (1 - P_{AL})^{n_L}$ (27)

This is the basic relationship that is used in all of the computations that follow.

7.04 For the model of the St. Marys River that we are considering, there are three kinds of accidents and associated probabilities.

P_{AG} - Probability of an Accident, Grounding

P_{AC} - Probability of an Accident, Collision

P_{ACI} - Probability of an Accident, Collision with Ice

It is assumed that the events described by these probabilities are entirely independent; that is, a grounding is entirely unrelated to a collision or a collision with ice. Although a single accident could possibly involve both a grounding and a collision, none have been recorded in the data available for the Great Lakes, therefore the probability of this event is assumed to be near zero. Based on the assumption that the events are independent, the probability of an accident is the probability that a grounding occurs, or the probability that a collision occurs, or the probability that a collision with ice occurs. Expressed in mathematical terms this becomes:

(2) $$P_A = P_{AG} + P_{AC} + P_{ACI}$$

7.05 Assume that a grounding or a collision can occur in any season but that a collision with ice can occur only during the time when ice present. The probability of an accident can be computed as follows:

N = Total number of transits for the season

n_G = Transits in good visibility

n_L = Total transits in low visibility

$N = n_G + n_L$

n_I = transits in ice

n_{IG} = Transits in ice in good visibility

n_{IL} = Transits in ice in low visibility

$$n_I = n_{IG} + n_{IL}$$

$n_I < N$ (i.e., n_I is a subset of N)

P_{AGG} = Probability of an accident, grounding, good visibility

P_{AGL} = Probability of an accident, grounding, low visibility

Applying the additional subscripts G and L in a similar manner to indicate events that occur in good visibility and low visibility, the probability of an accident becomes:

$$P_{AG} = 1 - (1 - P_{AGG})^{n_G} (1 - P_{AGL})^{n_L}$$

$$P_{AC} = 1 - (1 - P_{ACG})^{n_G} (1 - P_{ACL})^{n_L}$$

$$P_{ACI} = 1 - (1 - P_{ACIG})^{n_{IG}} (1 - P_{ACIL})^{n_{IL}}$$

and the overall probability of an accident is given by,

$$P_A = P_{AG} + P_{AC} + P_{ACI}$$

therefore the complete expression for the probabilty of an accident is

$$P_A = [1 - (1 - P_{AGG})^{n_G} (1 - P_{AGL})^{n_L}] + [1 - (1 - P_{ACG})^{n_G} (1 - P_{ACL})^{n_L}] + [1 - (1 - P_{ACIG})^{n_{IG}} (1 - P_{ACIL})^{n_{IL}}] \quad (3)$$

7.06 Probability of a Spill. The probability of a spill is given by:

$$P_S = P_{S/A} \times P_A$$

where

$P_{S/A}$ = Probability of a spill, given an accident

P_A = Probability of an accident

Since the model provides for three kinds of accidents, there are also three kinds of spills; that is, a spill resulting from a grounding, a spill resulting from a collision, and a spill resulting from a collision with ice.

$P_{SG/AG}$ = Probability of a spill, grounding, given an accident, grounding

$P_{SC/AC}$ = Probability of a spill, collision, given an accident, collision

$P_{SCI/ACI}$ = Probability of a spill, collision with ice, given an accident, collision with ice

As in case of an accident, a spill can occur as a result of grounding, or a collision, or a collision with ice. The probability of a spill then becomes:

(4) $P_S = P_{SG/AG} \times P_{AG} + P_{SC/AC} \times P_{AC} + P_{SCI/ACI} \times P_{ACI}$

Note that there is a single probability of a spill for each kind of accident because the chance of a spill once an accident has occurred does not depend on whether the accident occurred in good visibility or low visibility. Also, the probability of a spill resulting from a collision with ice is assumed to be the same as for a collision with a ship or fixed object.

Computation of Spill Risk

7.07 Probability of An Accident. Table VII-1 shows the probability of an accident on any single transit using records of the period 1974-1979. The number of accidents are recorded from Table VI-8 and the number of transits are recorded from Table VI-5. The probability of an accident is (Number of Accidents)/(Number of Transits).

7.08 Probability of a Spill, Given An Accident. There are no spills resulting from ship accidents recorded for the St. Marys River and Whitefish Bay during the years for which spill data are recorded (1974-1979). In order to perform an analysis for

TABLE VII-1 PROBABILITY OF AN ACCIDENT, ST. MARYS RIVER AND WHITEFISH BAY, DATA FOR 1974-1979

	GROUNDINGS		COLLISION		COLLISION WITH ICE	
	GOOD VIS	LOW VIS	GOOD VIS	LOW VIS	GOOD VIS	LOW VIS
NUMBER OF ACCIDENTS	27	5	43	1	15	1
NUMBER OF TRANSITS	63,635	3,042	63,635	3,042	4,677	400
PROBABILITY ACCIDENT (P_A)	.000424	.00164	.000676	.000329	.00321	.0025

this area, it is necessary to obtain data for a broader area. The principal threat of a spill resulting from an accident is from a tankship. Therefore, records of accidents and spills from tankships are examined for all of the Great Lakes. These data are used to determine the probability of a spill given an accident for tankships. It is then assumed that the probability of a spill as a result of an accident is the same in the St. Marys River as elsewhere in the Great Lakes. Accident data are, of course, site specific. This analysis therefore uses the probability of an accident for the St. Marys River.

7.09 Table VII-2 shows the probability of a spill given an accident for all the Great Lakes during the period 1974 through 1979. The number of spills are recorded from Table VI-12 and the number of accidents are recorded from Table VI-11. The probability of a spill given an accident ($P_{S/A}$) is (Number of Spills)/(Number of Accidents).

7.10 Probability of a Tanker Accident and Spill, Normal Season. The probability of a tanker accident and spill during the normal season is baseline data used to compare computed results for extended seasons. Since there have been no tanker accidents or spills in the St. Marys River/Whitefish Bay area during the time that spill data have been recorded, it becomes necessary to compute the baseline data as well.

7.11 The first step in computing tanker baseline data is to estimate the number of tanker transits that would occur in a normal season. This is done by reviewing records of tankers and estimating trends.

7.12 Table VI-1 shows tanker transits in the St. Marys River from 1974 to 1979. The trend is clearly for increasing annual tanker transits over this period of time, although some allowance must be made for the fact that the Soo Locks were open nearly all season from 1975 through 1979. Using recorded tonnage for the most recent year that data are available (1980), tanker transits are estimated to be 251. (The locks were open until 16 January 1981.) In the baseline year with the season ending on 15 December, some of these transits would be lost, however if the season were shorter there are likely to be more tranists in a shorter period of time. Assume that 224 transits occur in the shorter baseline year. This estimate is based on the approximate monthly percentage that could be expected to be lost during the time the locks are closed. This number must then be increased by the number of transits that go to Sault

TABLE VII-2 PROBABILITY OF A TANKSHIP SPILL RESULTING FROM AN ACCIDENT ALL GREAT LAKES, 1974-1979

	GROUNDING	COLLISION	EXPLOSION FIRE	FOUNDERING, CAPSIZING, FLOODING	HEAVY WEAHTER
NUMBER OF SPILLS	9	9	0	1	3
NUMBER OF ACCIDENTS	81	189	26	23	39
$P_{S/A}$	0.111	0.048	0	.043	.077
TOTAL ACCIDENTS	358				
TOTAL SPILLS	22				
OVERALL $P_{S/A}$	0.061				

$P_{S/A}$ - Probability of a spill, given an accident has occurred

Ste. Marie, Ontario, but do not go through the locks. This average number, based on the estimates of the petroleum shippers, is 112. (See Table VI-6.) Generally half of these transits are loaded ships and half are in ballast. The ships in ballast have a low probability of having a spill, therefore using all of these transits represents the worst case for probability of a spill. The total number of tanker transits estimated for the normal season is therefore 224 + 112 or 336. This number provides the basis for estimating monthly transits on Table VII-3.

7.13 Table VII-3 shows the estimated number tanker transits that would occur during each month of a normal season. These numbers are developed by taking the average percent of tanker transits for each month from Table VI-1 and distributing the estimated number of normal season transits according to these monthly fractions. The monthly transits in good visibility and low visibility conditions are then computed using average monthly visibility conditions shown on Table VI-4.

7.14 The probability of a tanker accident and a spill during a normal season can now be computed using the probability of an accident from Table VII-1, the probability of a spill given an accident from Table VII-2, and the estimated number of tanker transits in a normal season given Table VII-3. The details of this computation are shown for the normal season; the computations for the extended season alternatives are performed in the same way and the results are recorded on Table VII-4. The probability of a tanker accident during a normal season can be computed as follows using equation (3):

$$(3) \qquad P_A = [1-(1-.000424)^{322}(1-.00164)^{14}]$$
$$+ [1 - (1-.000676)^{322}(1-.000329)^{14}]$$
$$+ [1-(1-.00321)^{21}(1-.0025)^{1}]$$

where the first term is the probability of an accident, grounding, the second term is the probability of an accident, collision, and the third term is the probability of an accident, collision with ice. These computations yield the following results:

TABLE VII-3 NORMAL SEASON TANKER TRANSITS, ST. MARYS RIVER AND WHITEFISH BAY
NORMAL SEASON 1 APRIL TO 15 DECEMBER

These transits include the estimated numbers of tanker transits to Sault Ste. Marie, Ontario, but do not go through the Soo Locks.

TRANSITS MONTH	AVERAGE % TRANSITS	TOTAL TRANSITS	TRANSITS/VISIBILITY GOOD VIS	LOW VIS
APRIL				
ICE(73%)	7.5	18	17	1
CLEAR		7	7	0
MAY	11.8	40	39	1
JUNE	12.2	41	40	1
JULY	13.2	44	43	1
AUG	8.5	29	28	1
SEPT	10.2	34	33	1
OCT	13.3	45	43	2
NOV	13.5	45	41	4
DEC				
CLEAR	9.8	29	27	2
ICE(13%)		4	4	0
TOTAL	100.0	336	322	14

TABLE VII-4 PROBABILITY OF A TANKER ACCIDENT AND A SPILL DURING EXTENDED SEASON OPERATIONS

EXTENDED SEASON		ADDITIONAL DAYS
1	16 December To 15 January	31
2	16 December to 14 February	61
3	25 March to 1 April	4
4	18 March to 1 April	14
5	16 December to 1 April	106

SEASON	1	2	3	4	5	NORMAL
						(Normal Transits)
ADDITIONAL TRANSITS						
Good Visibility	23	33	3	5	42	322
Low Visibility	2	2	0	1	3	14
TRANSITS IN ICE						
Good Visibility	20	30	3	5	39	21
Low Visibility	2	2	0	1	3	1
PROB. ACCIDENT						
P_{AG}	0.0130	0.0172	0.00127	0.00376	0.0225	0.148
P_{AC}	0.0161	0.0227	0.00203	0.00370	0.0290	0.199
P_{ACI}	0.0669	0.0964	0.00959	0.01839	0.1244	0.068
P_A	0.0959	0.1363	0.0129	0.0259	0.176	0.415
PROB. SPILL						
P_{SG}	0.00144	0.0019	0.00014	0.000417	0.0025	0.0164
P_{SC}	0.00077	0.0011	0.000097	0.000178	0.0014	0.0096
P_{SCI}	0.00321	0.0046	0.000460	0.000883	0.0060	0.0032
P_S	0.0054	0.0076	0.000697	0.00148	0.0099	0.0292
LIKELY AMOUNT (gal)						
Grounding	91.6	120.6	9.0	26.5	158.7	1,223.3
Collision	.04	0.06	.005	.01	.07	.5
Collision, Ice	.16	.23	.023	.04	.30	.2
Total (gal)	92	121	9	27	159	1,224.0

$$
\begin{aligned}
P_{AG} &= 0.148 \\
P_{AC} &= 0.199 \\
P_{ACI} &= \underline{0.067} \\
P_{A} &= \overline{0.414}
\end{aligned}
$$

This means that the probability of a tanker accident in a single normal season is about 0.4. Put another way, in a period of 10 years, one could expect 4 tanker accidents and of these about 1.5 would be groundings (based on P_{AG}), 2 would be collisions, and about 0.5 would be collisions with ice.

7.15 The question might then be asked, how many years will pass before a tanker accident occurs? This can be determined numerically by solving equation (3) for a normal season for a period of several years until the probability of an accident approaches 1. The results of these computations are shown below.

YEAR	P_A
1	.41
2	.76
3	1.06

These computations indicate that a tanker accident should occur in just less than three years. Consider now how this result checks with accident records for the St. Marys River. In the six years covered by this analysis, there have been no tanker accidents. The result then, that there should be an accident in about three years, is slightly high. This variation can be explained, at least in part, by the fact that the probability of an accident on a single transit is computed using accident records for bulkers in the St. Marys River and the probability of a tanker accident is assumed to be the same. This assumption can be considered a worst case for tanker accidents because tankers are, on the average, much smaller than bulkers and they draw less water. Because they are smaller, they are less likely to have a collision and because they draw less water they are less likely to go aground. These results also tend to substantiate the opinions of the responsible Coast Guard officials reported in the operational assessment of ship accident potential. Experienced mariners believe that tankers are less likely to have an accident than bulkers. Using bulker accident rates for tankers gives a pessimistic result or a worst case estimate for tanker experience.

7.16 Probability of a Tanker Spill in a Normal Season. Using the probability of an accident just computed and the probability of a spill given an accident from Table VII-2, Equation (4) can be used to compute the probability of a spill.

$$(4) \quad P_S = 0.111 \times 0.148 + 0.048 \times 0.199 + 0.048 \times 0.067$$

$$\begin{aligned} P_{SG} &= 0.0164 \\ P_{SC} &= 0.0096 \\ P_{SCI} &= \underline{0.0032} \\ P_S &= 0.0292 \end{aligned}$$

This result shows that the probability of a tanker spill resulting from an accident is very low for a normal season. Using the reasoning applied before to accidents, in a 10 year period the probability of a spill would be about 0.3. Although it is not correct to say that the number of years to the first spill is the inverse of the probability of a spill in one year, this result does indicate that it may be about 30 years before a tanker spill that results from an accident occurs.

7.17 Likely Size of a Spill During the Normal Season. It would helpful to be able to compute the expected size of a tanker spill based on spill records and the computed probability that a spill will occur. In statistics, "expected value" is a measure of central tendency of a probability distribution. It is calculated by taking the weighted average of all possible values of a random variable, or in other words, by multiplying each value by its probability of occurrence then summing the resulting products (27). The problem in applying this concept to the present analysis is that the probability distribution must sum to one. In the case at hand, the complete probability distribution is not known and the values of the random variable, in this case spill size, are only known for the Great Lakes and not for the St. Marys River where the probability of a spill has been computed. Because of the limitation of data that are available, it is not possible to compute a true expected value for spill size.

7.18 In spite of these problems, it would still be desirable to define a measure of effectiveness that would show how much oil could be expected to be spilled for various season extension alternatives based on both spill records and the probability of a spill. The measure used in this analysis will be called the "likely size" of a spill to differentiate it from the statistical "expected value". The data available to show likely size of the spill are the average size of spill according to accident type taken from records of all spills in the Great Lakes (Table VI-12) and the computed probability of a spill for the St. Marys River. Thus by defining the following variables:

S_G = Average spill size, grounding
S_C = Average spill size, collision
P_{SG} = Probability of a spill, grounding
P_{SC} = Probability of a spill, collision
P_{SCI} = Probability of a spill, collision with ice

then

$$\text{Likely spill size} = P_{SG} \times S_G + P_{SC} \times S_C + P_{SCI} \times S_C$$

Using the average spill size from Table VI-12 and the probabilities of a spill in the normal season, this computation becomes:

$$\text{Likely spill size} = 0.0164 \times 74{,}589 + .0096 \times 50 + .0032 \times 50$$

Taking each element of this computation separately, the result becomes:

Likely Spill Size, Normal Season (gallons)

Grounding	1,223.3
Collision	.5
Collision, ice	.2
	1,224.0

This computation shows that the likely amount of oil discharged from a spill during the normal season is small, and that the chief threat of a significant discharge is a vessel grounding.

7.19 The likely spill size is also computed in a similar way for all of the season extension alternatives.

7.20 Probability of an Accident and Spill During Extended Season Operations. The probability of an accident and a spill during extended operations are computed using Equations (3) and (4) together with the estimated number of tanker transits during the extended seasons. The results are shown on Table VII-4. Note that the probability of an accident (P_A) during the extended season periods is relatively low. Even for the full season extension (Season 5), the probability of an accident is less than 0.2. For the other shorter seasons, the probability of an accident is much lower. The probability of an accident in ice is a much larger part of the total probability of an accident in the extended seasons than it is in the normal season. This result can be expected because the probability of an accident is the function of the number of transits, and nearly all of the extended season transits are in ice. The probability of a spill during the extended season is very low in every case, generally an order of magnitude less than the probability of a spill in the normal season.

7.21 Increased Risk in the Extended Season. Although the probability of a spill in the extended season is very low, it would be useful to establish some measure of the increased risk that may occur during the extended season. Consider as a measure of this risk, the probability of an accident per transit and the probability of a spill per transit. These values are shown in Table VII-5 below. The probability of an accident and a spill per transit is averaged over the five extended seasons. These ratios are then divided by the probability of an accident and a spill per transit for the normal season.

TABLE VII-5 PROBABILITY OF AN ACCIDENT AND SPILL PER TRANSIT

SEASON	P_A/transit x 10^{-3}	P_S/transit x 10^{-4}
1	3.8	2.2
2	3.9	2.2
3	4.3	2.3
4	4.3	2.5
5	3.8	2.2
Average	4.0	2.3
Normal Season	1.2	.87
Average/Normal	3.3	2.6

The results of this division (Average/Normal) show that although the probability of an accident or a spill per transit is very low, these ratios are about three times greater in the extended season than in the normal season. This increased risk is largely due to operating in ice.

7.22 Likely Spill Size in Extended Season. Table VII-4 also shows likely spill size for the extended seasons using the definition developed in paragraph 7.18. These results show that the likely additional discharge of oil during the extended season is small, generally less than or not much larger than the average size of operational spills from ships in the St. Marys River reported on Table VI-10. Even allowing for the potential of a large spill from a grounding, the low probability of a spill in the St. Marys River keeps the likely size of a spill in any single year or extended season small.

7.23 Confidence Intervals for Probability of an Accident and a Spill. A number of tests can be performed to estimate a level of confidence in computing the probability of a chance event. These tests generally require that the number of trials or observations be large and that the probability of the event not be too close to zero or 1. Many of the probabilities computed in this analysis are close to zero, but some significant observations can still be made about confidence intervals.

7.24 First consider the probability of an accident shown on Table VII-1. The probability of a grounding in good visibility is very low, therefore the standard mathematical test for confidence interval probably should not be applied. However, the size of the population observed, 63,635, does in itself provide a level of confidence in the result. In this very large sample, there were only 27 accidents over a period of six years. The reader can easily be persuaded that small changes in the number of accidents reported in some other interval of time would have only a small effect on the probability of an accident. For example, if in another six year period of time there were 10% more accidents, that is, 30 instead of 27, then the probability of an accident for the same number of transits would be .00047, which is very close to the result in this analysis. Similarly, if the number of groundings in low visibility were 10% higher, then the probability of an accident would be .0018, which is quite close to the value shown on Table VII-1. One may conclude then, that the probability of an accident for a large number of transits is quite accurate because a moderate change in the number of accidents would cause only a small change in the result.

7.25 Now consider the probability of a tanker accident computed for a normal season. Referring to Table VII-4, this probability (rounded-off) is .42, which is not close to zero or one and the computation is based on a large sample. The confidence interval can therefore be checked using a standard test. The 90% confidence interval is given by:

$$1.64\sqrt{\frac{P\ (1\ -P)}{N}} \qquad (28)$$

where P is the probability of the event and N is the sample size. With P = 0.42 and N = 336 tanker transits per year, the result is .04. That is, one can be 90% confident that the required probability is between 0.46 and 0.38. Table VII-6 shows confidence intervals for the normal season plus season extension alternatives 2 and 5. Confidence intervals are not estimated for seasons 1,3, and 4 because the sample size is too small.

7.26 Table VII-7 shows the confidence interval for the probability of a spill given an accident using data from Table VII-2. Although the probability of these events is small, the sample size is adequate so the result can be considered as a fair representation of the confidence interval. A confidence interval for the probability of a spill in the extended seasons cannot be established because the probability of the event in each case is very close to zero.

7.27 General Assessment of Tanker Spill Hazards. A recent Sea Grant Study of tanker operations in the Great Lakes found that port calls are more closely related to the occurrence of spills than either distance covered or tonnage carried (29). Operational spills generally occur during loading and unloading operations in port. In addition, spills resulting from groundings and collisions are most likely to occur in the congested waters of harbors. This result is significant to the current study because the St. Marys River/Whitefish Bay area is not marked by intensive operations in harbors, therefore spills resulting from ship accidents should be lower than Great Lakes averages.

TABLE VII-6 CONFIDENCE INTERVALS, PROBABILITY OF AN ACCIDENT

SEASON	P_A	CONFIDENCE RANGE	90% CONFIDENCE INTERVAL
Normal	.42	+ .04	.38 - 0.46
2	0.14	+ .09	.05 - 0.23
5	0.18	+ .09	.09 - .27

TABLE VII-7 CONFIDENCE INTERVALS, PROBABILITY OF A SPILL GIVEN AN ACCIDENT

ACCIDENT	$P_{S/A}$	CONFIDENCE RANGE	90% CONFIDENCE INTERVAL
GROUNDING	0.11	+ .06	.05 - .17
COLLISION	0.05	+ .03	.02 - .08

7.28 The Sea Grant Study also found that in the Great Lakes tankers and bulkers together average about 2 spills greater than 100 gallons per 1000 port calls. This number is quite low as compared to a combined tanker spill rate of 4.76 spills per 1000 port calls in five U.S. salt water ports (29). This low incidence of spills shows that the petroleum distribution system on the Great Lakes provided by a small, well regulated U.S. and Canadian fleet, presents a lower hazard to a spill than the multi-national assortment of ships visiting salt water ports.

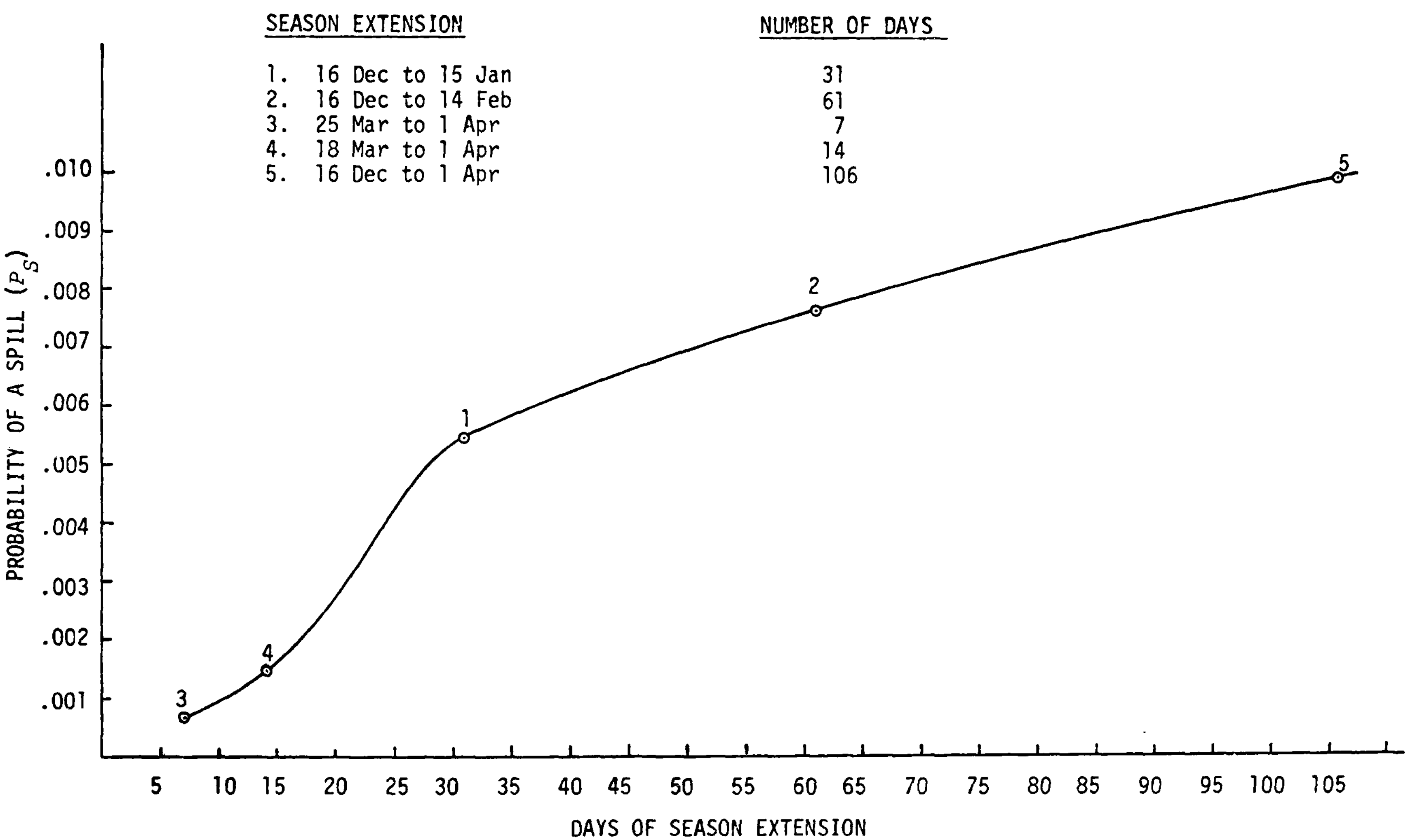
Summary of Results

7.29 The final, most significant result of this analysis is the probability that a spill would occur during the various season extension alternatives. The probability of a spill computed in this analysis depends on the number of vessel transits that occur in the St. Marys River; however, navigation season limits are established in terms of days and dates of closing, not transits. Consider, therefore, the probability of a spill during the selected season extension periods in terms of the number of days that are included in these periods.

7.30 Figure VII-1 shows a plot of the probability of a tanker spill plotted against the number of days in each season extension. Seasons 3 and 4 are at the low end of this curve. These are both very short early seasons beginning in March a few days before the normal season opening of 1 April. The probability of a spill during these early seasons is very low based on a low number of transits expected for an early river opening. The success of these seasons would probably depend on weather conditions. In a season with a relatively warm winter and an early breakup, Seasons 3 and 4 would probably be feasible. In a year with a cold winter and a late breakup, the ice in Whitefish Bay and the St. Marys River would probability prevent an early opening.

7.31 Season extension periods 1, 2, and 5 represent additions of one month, two months, and three and one-half months to the normal season. The probability of a spill during these seasons is relatively low and increases gradually to full season operations. The probability of a spill per day of season extension is actually decreasing as days of season extension are added. The probability of a spill during the additional 106 days that

FIGURE VII-1 PROBABILITY OF A TANKER SPILL VS. DAYS OF SEASON EXTENSION



are required for full season operations is about 0.01, which means there is about a 1 in 100 chance of a tanker spill during this added time in any given year. The threat of a spill during extended season operations must therefore be considered to be low.

VIII. CONCLUSIONS

8.01 The probability of a spill resulting from a vessel accident in the St. Marys River/Whitefish Bay area is low. Since there have been no spills resulting from ship accidents during the time covered by spill records (1974-1979), the probability of an accident and a spill are computed using accident rates for the St. Marys River and spill rates for all of the Great Lakes. These computations show the probability of a tanker accident in a normal season to be about 0.4 and the probability of a spill to be about .03. These numbers are considered to be somewhat high because the probability of a tanker accident was assumed to be the same as a bulker; however, tankers can be expected to experience lower accident rates because they are generally much smaller than bulkers and draw less water.

8.02 The probability of an accident and a spill is low during the proposed extended seasons. For full season extension, the probability of an accident is less than 0.2 and the probability of a spill is about 0.01. This means that there is a 1 in 100 chance of a tanker spill during the time added for full season operations.

8.03 Although the probability of an accident and a spill are low during the extended season alternatives, the threat of an accident or a spill per transit during late season operations in ice is about three times that of a normal season.

8.04 A tanker grounding is the single significant threat to a large spill. Although the probability of a tanker grounding and spill is low, the spill that may result from this type of accident can be quite large.

8.05 Senior U.S. Coast Guard officers responsible for safe navigation in the St. Marys River believe the threat of a spill from ships operating in ice is low. This is because the danger of collision is low in winter when ships are escorted by Coast Guard icebreakers, and because the danger of a grounding is low when ships are constrained to remain in a channel cut in the ice. In addition, ships using high power to push through ice are stopped and held in place when the power is removed. This generally prevents either a collision or a grounding.

8.06 An engineering analysis indicates that there is a danger of a ship being holed by collision with ice or from the crushing force of ice, but because most ships have double hulls, these accidents do not necessarily result in an oil spill. Further, because the hole is likely to be near the waterline, the resulting spill may be small.

IX. RECOMMENDATIONS

9.01 Valuable planning information can be obtained by using records of vessel operations to determine the threat of an oil spill in critical shipping choke points. Because recent records provide the best data base for predicting future trends, it is recommended that the data required to predict these trends be collected on a continuing basis. Further, it is recommended that new computations of spill threat be made periodically to assess the impact of changes in traffic levels and operating practices.

9.02 Because tanker groundings are the single major cause of large spills in the Great Lakes, it is recommended that all possible steps be taken to reduce the risk of groundings in critical vessel traffic areas. As an example of the kinds of actions that can be taken, it is recommended that the entire width of the Middle Neebish Channel be dredged to a project depth of 27 feet to reduce the danger of an upbound loaded tanker from going aground in this hazardous stretch of channel. Other actions that might be taken include improving aids to navigation in dangerous sections of the channel and providing positive control of all tankers in the St. Marys River to reduce the possibility of an accident.

9.03 Oil spills present a greater threat to the environment in the Great Lakes than in ocean areas because these inland seas form a closed system with little chance for the oil to escape. In addition, oil spilled in a winter ice environment is more difficult to control and recover. It is therefore recommended that immediate steps be taken to identify technology needed to respond to spills in ice in the St. Marys River, Whitefish Bay, and in other locations in the Great Lakes where severe ice conditions occur and there is the threat of a spill. The recommended effort would identify the needed technology, and if required, develop a conceptual design of a spill response system that would be effective in a Great Lakes ice environment.

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